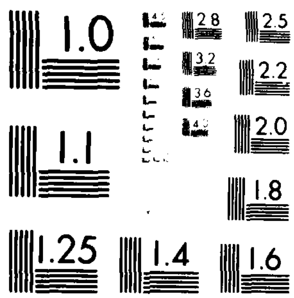
AD-A107 072 ECLECTECH ASSOCIATES INC NORTH STONINGTON CT F/G 17/7
SIMULATOR EVALUATION OF ELECTRONIC RADIO AIDS TO NAVIGATION DIS--ETC(U)
SEP 80 R B COOPER, K L MARINO DOT-CG-835285-A
UNCLASSIFIED EA-80-U-88 USCG-D-69-80 NL

1 of 2



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

CG-D-59-80

LEVEL II

12

AD A107072

SIMULATOR EVALUATION OF ELECTRONIC RADIO AIDS TO NAVIGATION DISPLAYS — THE MINIEXPERIMENT

Eclectech Associates, Inc.
North Stonington Professional Center
North Stonington, Connecticut 06359

DTIC
ELECTE
NOV 9 1981
H

September 1980

Interim Report

Document is available to the U. S. public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590

DTIC FILE COPY

81 11 06 160

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

Technical Report Documentation Page

1. Report No. USCG-D-59-80	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Simulator Evaluation of Electronic Radio Aids to Navigation Displays — The Miniexperiment		5. Report Date September 1980
		6. Performing Organization Code
7. Author(s) R. B. Cooper and K. L. Marino		8. Performing Organization Report No. EA-80-U-88
9. Performing Organization Name and Address Eclectech Associates, Inc. North Stonington Professional Center North Stonington, Connecticut 06359		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-CG-835285-A
		13. Type of Report and Period Covered Interim Report
12. Sponsoring Agency Name and Address Department of Transportation U. S. Coast Guard Office of Research and Development Washington, D. C. 20590		14. Sponsoring Agency Code

15. Supplementary Notes

None

16. Abstract

This report describes a simulator evaluation of electronic radio aids to navigation displays conducted for the purpose of trading off display information effectiveness with operational requirements and shipboard system cost. The miniexperiment, a predecessor to more lengthy experimentation, utilized an abbreviated scenario to operationally simulate 18 display formats. Six digital, ten graphic, and two perspective displays were evaluated. The digital display was designed to provide trackkeeping and turning information that would enable a pilot to transit the waterway while using an inexpensive digital (alphanumeric or numeric only) display. The graphic display was designed to provide a pictorial representation of ownship in the waterway similar to the way it is viewed on radar, contemporary collision avoidance, or navigation option displays. The perspective display was designed to portray the perspective scene as viewed out the forward bridge windows. Pilot performance using each of the displays is discussed and analyzed, and seven displays were recommended for further evaluation in the full-scale experiment.

17. Key Words ship simulator, bridge display, bridge equipment, electronic aids to navigation, navigation displays, digital navigation display, graphic navigation display, (see 17 continued)	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	121	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

17. KEY WORDS (CONTINUED)

perspective navigation display
shiphandling
trackkeeping
crosstrack variability
crosstrack distance
rudder actuations
magnitude of rudder
turning cues
steering cues
motion cues
orientation cues
ownship image cues
vector cues

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Captain Donald A. Feldman, Chief of the Navigation System Technology Branch of the United States Coast Guard, for his close personal support of the radio aids display evaluation program and his timely guidance throughout the conduct of this experiment. The significant contributions of Mr. Karl A. Schroeder during the planning and analysis phases of the study also are greatly appreciated.

Special recognition is due to the members of the Northeast Marine Pilots' Association who took time out of their busy schedules to act as subjects for the experiment. Each acquired an enthusiastic interest in the project and provided valuable insight as potential users of radio aids to navigation systems.

Accession For

A

PREFACE

The simulation experiment described herein is the first of a multiple experiment program for the operational evaluation of radio aids to navigation displays. The intent of the overall program is to investigate navigational safety as a function of display cost, complexity and system error characteristics. The results will define the requirements for an electronic display which will allow safe pilotage of vessels in poor visibility conditions keeping in mind all economic, technological and feasibility limitations.

The report describes abbreviated 12 minute simulations for selecting the most effective displays from among 18 original candidates. This experiment, known as the *miniexperiment*, was conducted using "perfect position" information for displaying ownship in the world. Those displays selected in the miniexperiment will be further tested in full-length (1 hour) scenarios, still using perfect position inputs. This more stringent testing of formats with perfect position information is known as the RA-1 experiment. The remaining one or two "benchmark" displays will again be simulated, only this time in a noise environment of known proportions, using specified tracking filter characteristics and filter aiding techniques. This will be known as the RA-2 experiment. Both the RA-1 and RA-2 experiments will be presented in subsequent documentation.

"The ultimate objective of the program will be realized by a combination of the performance metric, various signal to noise ratios and filter bandwidths into a definitive statement about the ability of a pilot to navigate a restricted waterway in limited visibility conditions."[1]

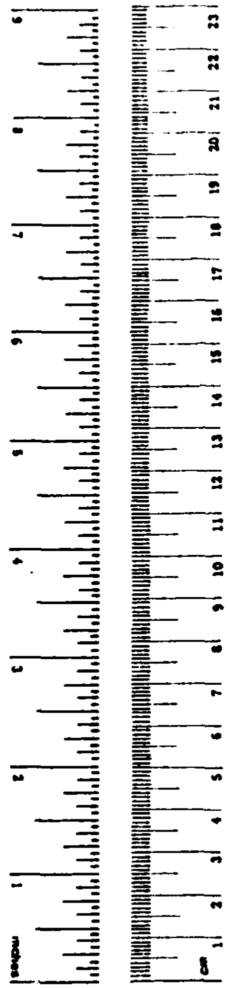
[1] United States Coast Guard, An Approach to the Study of Electronic Displays for Use in Restricted Waterways, a position paper, December 1979.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

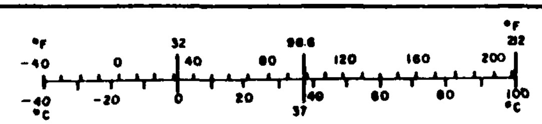


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Section 1

CONCLUSIONS AND RECOMMENDATIONS

1.1 SUMMARY OF CONCLUSIONS

The overwhelming conclusion of the miniexperiment is that of the three display concepts examined, the GRAPHIC display produced the most satisfactory results. This was evident both in a comparison of subject performance and individual preference. Table 1 shows a summary of this performance as interpreted from the statistical analyses of Section 5.

Figure 1 best illustrates the findings. It is a graphic presentation of the mean track (center of gravity) of ownship and +/- two crosstrack standard deviations of all tracks made when each type of display was used. These plots define the envelope that would contain 95 percent of all ship tracks for a population of transits under similar experimental conditions. A review of Figure 1 shows all mean tracks to originate in the center of the channel and with comparable crosstrack variability. In the bend, the mean track with the DIGITAL display is significantly closer to the point of the bend than either of the other displays. This suggests a premature or early initial turn rudder for the turn radius required by the bend.

It is concluded that by designing the leadline of the digital display too far from the bend, pilots were influenced to turn early resulting in an "undershoot" of the bend. The experiment suggests that either (1) the leadline should be located to accommodate a larger overall rudder angle (i.e., larger turn rate), or (2) the selection of a turn initiation point should be left up to each individual pilot and should be implemented as a manual operation via selector knob. In general, the

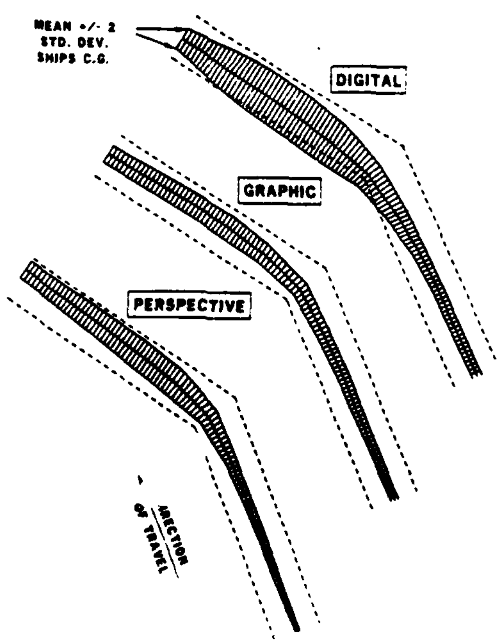


FIGURE 1. SUMMARY OF TRACKKEEPING BETWEEN DISPLAY CONCEPTS

TABLE 1. SUMMARY OF RESULTS

	TRACK-KEEPING		TURNING	
	APPROACH LEG	EXIT LEG	INITIAL RUDDER	CHECK RUDDER
DIGITAL VARIABLES				
Steering Cues				
- none	●		●	
- course error	●	●		
- heading to steer		●		
Turning Cues				
- distance to leadline			●	
- time to leadline	●			
GRAPHIC VARIABLES				
Motion Cues				
- true motion				●
- relative motion			●	
Orientation Cues				
- track up		●	●	
- head up	●			
Vector Cues				
- heading			●	●
- course				
Ownship Image Cues				
- scaled			●	
- symbolic (+)				
PERSPECTIVE VARIABLES				
Field of View				
- 60 degrees	●			
- 90 degrees				●

● indicates superior pilotage performance
interpreted from statistical analysis of measures (Section 4)

overall concept of presenting digital information for trackkeeping and turnmaking on a radio aids to navigation display appears plausible given adequate user familiarization and effective display design.

High crosstrack variability with the DIGITAL display beyond the bend indicates inconsistency among subjects in the application of their check rudder and considerable difficulty in steadying up. This difficulty was primarily attributed to subject inexperience with the DIGITAL display.

By the end of the second leg, as shown in Figure 1, mean tracks for all but the PERSPECTIVE display had returned to the channel centerline. This suggests that with the PERSPECTIVE display pilots either could not track down the centerline or were unaware that they were not in the center. A comparison of pilotage performance between when subjects used the different PERSPECTIVE displays indicates that the 60-degree field of view display was the primary contributor to this trackkeeping difficulty. This is shown in Figure 2. Apparently the additional 30 degrees in the field of view of the 90-degree display provided more effective information for portraying ownship's position in the channel.

In general, the GRAPHIC display produced the most favorable results, but even among the graphic variables there were trackkeeping differences. These differences are shown in Figure 3. Overall, the turn motion, track-up GRAPHIC display produced the most desirable track plots of the displays that were evaluated. Subsequent findings of the experiment suggest that the ship's image, scaled or symbolic, had very little effect on overall performance; however, certain combinations of orientation, motion, and vector type did. The GRAPHIC concept in general produced superior performance over the other concepts for those pilotage tasks performed in the experiment.

1.2 MAJOR RECOMMENDATIONS

As a result of wide subject variability, the heading vector was shown to be easier to implement and understand by subjects than the course vector. This is attributed to the subjects' familiarity with heading vectors and their general lack of appreciation of how a course vector should appear in a turn. Additional training in the use of a course vector is recommended prior to further experimentation. Also, it is suggested that an investigation into the use of a combined heading and course vector display should be pursued.

The symbolic (+) presentation of ownship is considered inappropriate for further evaluation on the radio aids to navigation displays. A navigation system with the potential implementation capabilities such as those suggested require an accuracy resolution achievable only by the scaled ship's image. This feature is not considered a significant cost factor; given the benefit to shiphandling performance and subject acceptance it should be included in all subsequent GRAPHIC display experiments. Reduction of the GRAPHIC display scale can be expected to yield further increases in shiphandling performance as a function of improved spatial resolution.

As a result of the miniexperiment findings, it is recommended that two GRAPHIC displays, both track up, true motion with a scaled ship's image be included in the RA-1 experiment. The display variables to be reevaluated in the full length scenario are heading vector and course vector. Two additional GRAPHIC displays for the presentation of predictor steering information are also suggested for evaluation by RA-1.

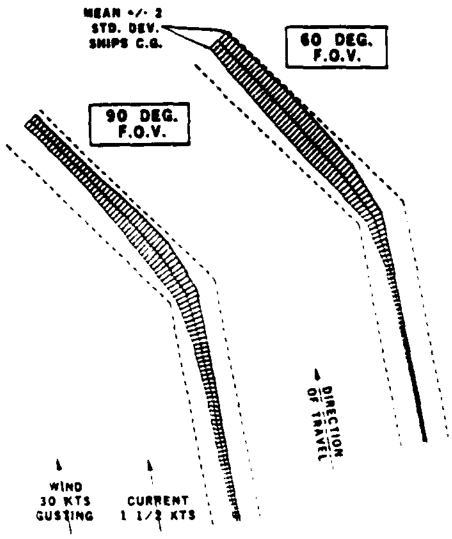


FIGURE 2. SUMMARY OF TRACKKEEPING BETWEEN PERSPECTIVE DISPLAYS

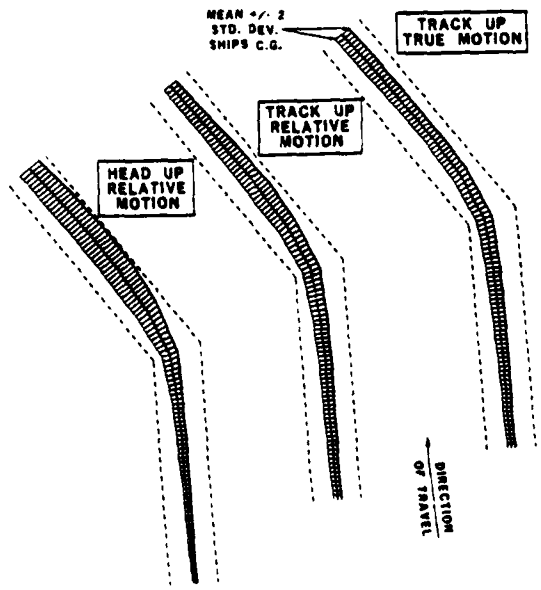


FIGURE 3. SUMMARY OF TRACKKEEPING BETWEEN GRAPHIC DISPLAYS

The PERSPECTIVE display while experiencing a significantly higher incidence of rudder activity through the bend, and subsequent difficulty returning to the exit leg centerline, should be further evaluated in a more challenging scenario than that experienced in the miniexperiment. Differences in performance between the 60-degree and 90-degree field of view displays were substantial. Based on (1) subject opinions, (2) the ability to see more of the channel abeam for an easier determination of drift angle, and (3) the ability to see the point longer through a bend, the 90-degree field of view is suggested for use in all subsequent, full-length simulations. No modifications to the PERSPECTIVE display are warranted as a result of the miniexperiment analysis. As a result of the miniexperiment findings it is recommended that the 90-degree perspective display be included in the RA-1 experiment for reevaluation in the full length scenario.

Results of the DIGITAL display analysis support its effectiveness both in trackkeeping through straight legs and in turnmaking. Operational goals of the DIGITAL concept, however, were not compatible with those of the other concepts in that a turn radius of 0.8 nm requiring only a 10-degree rudder was described by the DIGITAL display while evidence suggests that the simulated turn would normally be executed using 15- to 20-degree rudder.

As a result, significant undershoot of the turn is indicated. Modification of the DIGITAL program to accommodate a 0.5 nm radius turn (e.g., requiring a 20-degree initial rudder) will ensure both acceptable tracking through the turn and bring the operational requirements more in line with the GRAPHIC and PERSPECTIVE displays.

Analysis of performance when using steering cues shows that course error was either better understood by the subjects or more trusted than heading to steer. When no steering cues were provided, subjects experienced a greater variability in attempting to return to the channel centerline beyond the turn. Other variability measures at initial rudder suggest that all DIGITAL runs were made equally well regardless of whether steering cues were provided or not. The presence of this significant variability, however, does suggest that the steering cues (at least course error) should be further examined in a scenario with lengthy straight legs.

The display of time to leadline instead of distance to leadline was shown to promote small variability among subject groups particularly in the application of initial rudder. End results of the turn maneuver, however, show no overshoot of the bend and comparable excellent alignment on the centerline after the turn was completed. This suggests that the variability in initiating the turn rudder was not sufficient to effect the overall performance in what evolved as a very gradual maneuver. Regardless of whether time or distance cues are presented on the DIGITAL display, little effect on individual determination of the haul point is expected.

As a result of the miniexperiment findings it is recommended that two DIGITAL displays be included in the RA-1 experiment, one substantially modified from the miniexperiment. The modified display would include no turnmaking information and both would require manual selection of the turn initiation or haul point by the operator.

Measures and statistical techniques employed in the miniexperiment are considered adequate for the somewhat limited analysis which was required. Among

conclusions gleened from the experiment is the need for a more in-depth analysis of trackkeeping including track means and standard deviation (*variability*) plots especially through the straight legs and within the bend. A more comprehensive, structured retrieval of subject appraisals and display critique is also warranted.

Section 2
EXPERIMENT OVERVIEW

The evaluation of electronic radio aids to navigation displays is being conducted to determine:

1) a highly effective display(s) for the presentation of navigation information

2) tradeoffs of cost versus effectiveness for the design of navigation display systems

3) impact of display design on operator performance and safe navigation through restricted waterways in poor visibility

4) system filter requirements for achieving acceptable pilotage with a highly effective display(s)

5) noise parameters which can be tolerated by the resultant display(s) and filter(s) to achieve acceptable pilotage

The study diagramed in Figure 4 began by evaluating, through operational simulation, numerous promising state-of-the-art display concepts using perfect information for positioning ownship. An abbreviated, miniexperiment was conducted on 18 different display formats to eliminate many of the original variables, recommending only the most effective ones for more extensive, more costly RA-1 evaluation. The miniexperiment and recommendation of display formats for further evaluation is the subject of this report.

2.1 DISPLAY DESIGN RATIONALE

Three unique display technologies were evaluated in the miniexperiment as a function of their potential cost of design and implementation in real world applications. The concept of display technology in the low, moderate, and high cost categories is one of visual display capability (e.g., graphics versus alphanumerics), computer capability (e.g., speed, memory), and computer program development requirements (e.g., geographic inputs, shipboard sensor). See Section 6.2 for a discussion of the cost and hardware analysis of each display.

The lowest cost display is represented as an all DIGITAL readout of parameters such as shown in Figures 5 and 6. It is assumed that alphanumeric and numeric only displays would not be significantly cost distinctive. For test purposes the digital readouts are displayed on a cathode ray tube (CRT), while actual applications of this type display might use light emitting diode (LED), liquid crystal display (LCD), plasma panel (gas discharge), or multiple-projection readouts.

The more costly display technology is represented by a CRT display capable of both alphanumeric and/or graphic presentation such as shown in Figure 7. This technology requires computer capabilities, provisions for data storage and retrieval, and input methods whether manual or automatic. Actual cost of this type of equipment can range from a moderately priced system presently being developed for the United States Coast Guard by Applied Physics Laboratory to the more idealistic approach for predictor steering systems or perspective view displays. The moderately priced APL system, which will be represented in simulation as a GRAPHIC display, uses a limited graphics and alphanumerics CRT, a microprocessor

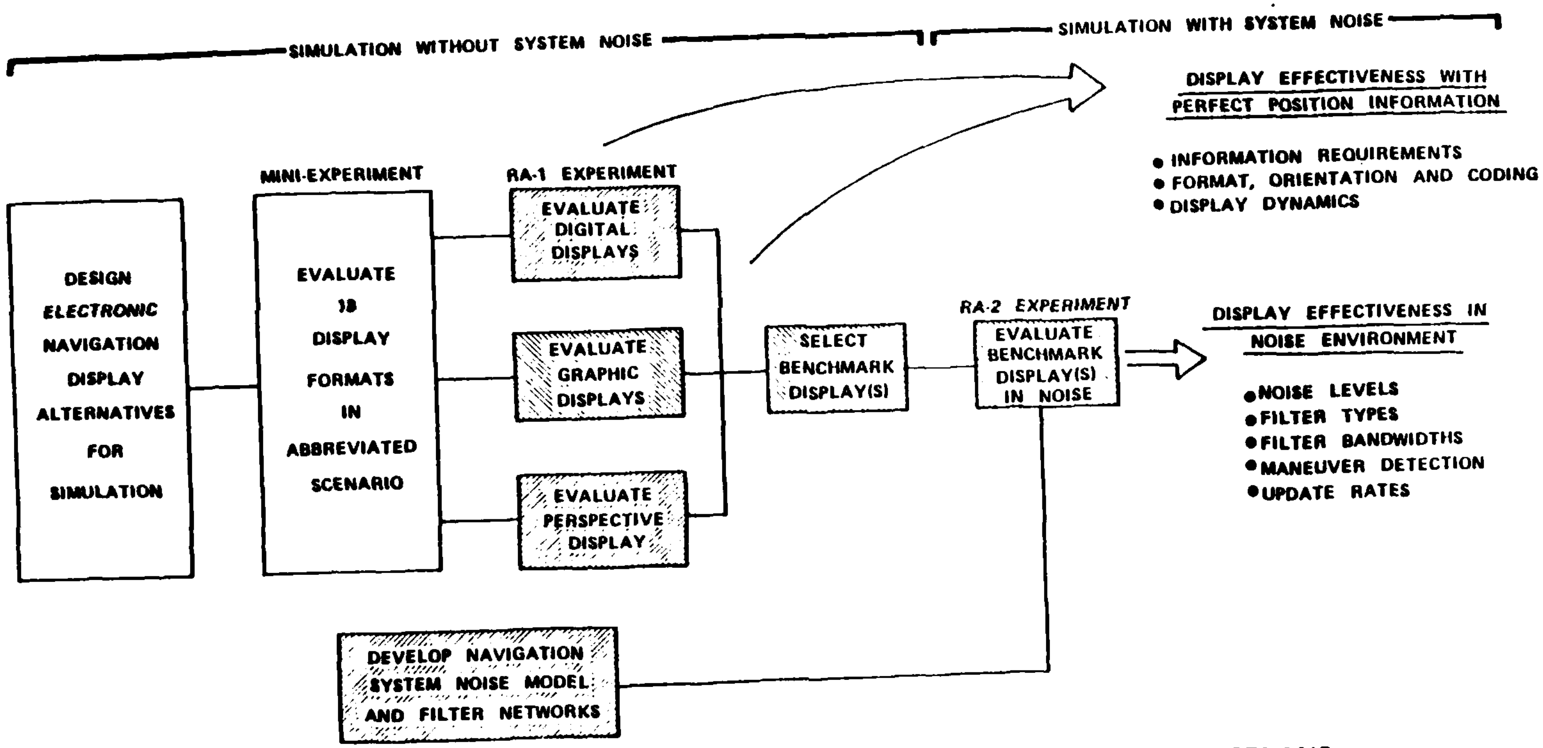


FIGURE 4. PLAN FOR THE EVALUATION OF ELECTRONIC NAVIGATION DISPLAYS

CROSSTRACK DISTANCE:	24 FT ➤
CROSSTRACK SPEED:	28 FT/MIN ◄
COURSE ERROR:	4 DEG ◄
TURN RATE:	1 DEG/MIN ◄
DISTANCE TO LEADLINE	0.3 NM

FIGURE 5. EXAMPLE OF DIGITAL DISPLAY AT BEGINNING OF EXPERIMENT

CROSSTRACK DISTANCE:	784 FT ➤
CROSSTRACK SPEED:	1857 FT/MIN ➤
TURN RATE:	20 DEG/MIN ◄
RECOMMENDED TURN RATE:	24 DEG/MIN ◄

FIGURE 6. EXAMPLE OF DIGITAL DISPLAY AT BEND

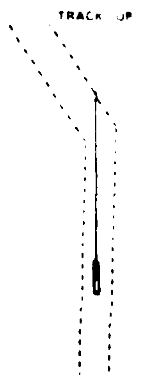


FIGURE 7. EXAMPLE OF GRAPHIC DISPLAY

and relatively inexpensive memory and input techniques. The moderately priced category will also include a PERSPECTIVE display with a view similar to what the pilot sees out the forward windows (see Figure 8).

Capabilities of this moderately priced category will fluctuate to some degree with the cost of system definition and procurement. Regardless of this variability, however, its cost remains unique compared to that of extensive, high-speed capabilities required for computing ship's hydrodynamic characteristics, navigational data, chart information, and ship operating parameters characteristic of even more sophisticated systems. For this reason a high priced category will also be evaluated in the future RA-1 experiment. This category will consist of one GRAPHIC display which exhibits a computed track prediction based upon hydrodynamic algorithms and ship status inputs (e.g., predictor steering display). Each of the DIGITAL, GRAPHIC, and PERSPECTIVE displays contain a number of unique information or format characteristics. The introduction of color to any of the displays could have an impact on their cost. This capability, however, is not being addressed in the program.

Because some of the displays were obviously more beneficial or detrimental to effective display utilization than others, it was decided to perform inexpensive, abbreviated simulations before engaging in the more costly, full-length evaluation. As a result, a miniexperiment was conducted using the displayed information described in Table 2 as a variable.

The predictor steering format of the GRAPHIC display was not examined in the miniexperiment since previous research had documented its numerous benefits, making its inclusion in the full-length RA-1 experiment inevitable.

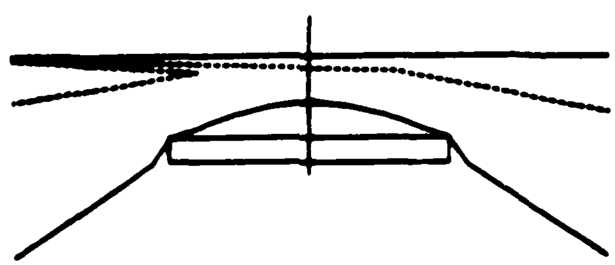


FIGURE 8. EXAMPLE OF PERSPECTIVE DISPLAY

TABLE 2. MINIEXPERIMENT VARIABLE LEVELS

DIGITAL DISPLAY (low cost)

- Crosstrack distance from centerline
- Crosstrack velocity
- Course error
- Heading to steer
- Turn rate
- Recommended turn rate
- Distance to leadline
- Time to leadline

GRAPHIC DISPLAY (moderate cost)

- Track-up, true motion
- Track-up, relative motion
- Head-up, relative motion
- Ship heading vector
- Ship course vector
- Scaled ship image
- Symbolic (cross) ship image

PERSPECTIVE DISPLAY (moderate cost)

- 60 degree field of view
- 90 degree field of view

2.2 DESIGN OF THE MINIEXPERIMENT

Rationale for the design of a miniexperiment to eliminate ineffectual or potentially unsafe displays was based on anticipated display usage and known shiphandling requirements. It was decided that to be considered a candidate for full scenario simulation the display must at least be capable of guiding the pilot safely around a single 35-degree bend in the channel. If this could not be achieved the display's benefit would be significantly diminished regardless of its advantages in other segments of the scenario.

The miniexperiment originated approximately 0.75 nautical miles (nm) from the bend and terminated in 12 minutes, approximately 0.75 nm above it. This provided ample time for the subjects to demonstrate some trackkeeping ability with the display, initiate and conduct a 35-degree course change within defined boundaries, and steady on the new trackline. All environmental conditions and ship control characteristics of the full-length scenario were contained in the miniexperiment. This will provide for additional validation by comparing the two experiments and relating resultant performance to comparable runs in the AN-CAORF[2] and AN-VISUAL[3] experiments.

[2]Eclectech Associates, Inc., Aids to Navigation Presimulation Report, AN-CAORF, United States Coast Guard, September 1979.

[3]Eclectech Associates, Inc., Aids to Navigation Presimulation Report, AN-Visual Experiment, United States Coast Guard, October 1979.

Section 3

EXPERIMENTAL DESIGN

The miniexperiment was intended as a brief overview of the overall effectiveness and potential operator acceptance of various formats of DIGITAL, GRAPHIC, and PERSPECTIVE radio aids to navigation displays. These display formats represented the primary variable of the experiment and as such, received priority treatment in the experimental design. Individual subject differences, order effects (learning), and secondary effects such as helmsman performance were also considered. Each subject was administered explicit instructions on the use of the display prior to every run. The instructions are presented in Appendix A.

3.1 DISPLAY VARIABLES

The DIGITAL display was designed to provide trackkeeping and turnmaking information that would enable a pilot to transit the waterway while using an inexpensive DIGITAL (alphanumeric or numeric only) display. The display could conceivably be handheld or bridge mounted, but would receive its information from a microprocessor and high precision radio navigation system. Table 3 shows the variable levels simulated in the evaluation of the DIGITAL display.

Only one level of trackkeeping information (TKI) was used along with each level of turnmaking information (TMI). These levels were counterbalanced among subjects in the experimental design to accommodate the learning effect. When using the DIGITAL display, the following information was provided to each subject in the first leg:

1) CROSSTRACK DISTANCE shown in feet to the right or left of the channel centerline with its direction indicated by arrows,

2) CROSSTRACK SPEED shown in feet per minute with an arrow pointing in the direction that ownship is moving,

3) TURN RATE shown in degrees per minute with an arrow indicating the direction right or left,

4) DISTANCE TO LEADLINE shown in nm. The leadline is the point at which the turn should be initiated. It is calculated in advance based on making the turn with a standard (10 degree) rudder, or

TABLE 3. DIGITAL DISPLAY VARIABLE

	TRACKKEEPING INFORMATION (TKI)	TURNMAKING INFORMATION (TMI)
LEVEL 1	CROSSTRACK DISTANCE CROSSTRACK SPEED	TURN RATE RECOMMENDED TURN RATE DISTANCE TO LEADLINE
LEVEL 2	CROSSTRACK DISTANCE CROSSTRACK SPEED COURSE ERROR	TURN RATE RECOMMENDED TURN RATE TIME TO LEADLINE
LEVEL 3	CROSSTRACK DISTANCE CROSSTRACK SPEED HEADING TO STEER	

5) TIME TO LEADLINE shown in minutes. This is continuously calculated based on ownship's speed.

Once ownship has reached the leadline, information for CROSSTRACK DISTANCE and CROSSTRACK SPEED is calculated to the new leg. TIME TO LEADLINE or DISTANCE TO LEADLINE disappears and the subject is shown a RECOMMENDED TURN RATE which he must try to match with ownship's TURN RATE. This recommended turn rate is continuously calculated so that if the subject is able to achieve and maintain it, he will arrive on the centerline of the new leg even taking into account wind and current factors. Once ownship's heading is within 5 degrees of the new leg, RECOMMENDED TURN RATE disappears and TIME TO LEADLINE or DISTANCE TO LEADLINE to the next bend is presented. Thus alphanumeric information is the only guidance which pilots receive when using the DIGITAL display. There were six possible combinations of the DIGITAL format variable and each subject was administered the miniexperiment scenario using all six as shown in Table 4, the experimental design.

The GRAPHIC display was designed to provide a pictorial representation of ownship in the waterway very similar to the way it is viewed on radar or contemporary collision avoidance and/or navigation option displays. This display would be cabinet mounted requiring a CRT with accompanying support electronics and a data processor system. As such, it could conceivably provide a large variety of display features or could be limited to a few. Thus, the basis for evaluating the GRAPHIC display was to determine which of the display features are most effective and if any combinations are actually detrimental to safe, effective shiphandling.

Table 5 shows the variable levels simulated in the evaluation of the GRAPHIC display. Note that three display orientations (DO), two different types of ship vectors (SV), and two different ship images (SI) were tested. These levels were also counterbalanced among subjects to accommodate the learning process.

When using each GRAPHIC display it was oriented as one of the following:

1) TRACK-UP, TRUE MOTION where ownship originates 1/4 the display diameter from the bottom of the screen and resets after it has traveled 3/4 of the distance across the screen. With the track-up mode, the picture comes on with the channel centerline oriented up and ownship moving through it. Once the turn is completed (approximately one ship length beyond the turn) the display automatically changes to the new track-up and ownship resets to the bottom of the screen.

2) TRACK-UP, RELATIVE MOTION in which ownship's image always remains in the center of the screen. Channel centerline is always oriented up and ownship revolves relative to it.

3) HEAD-UP, RELATIVE MOTION in which the bow of ownship and subsequently the gyrocompass heading is always up and all motion revolves around ownship.

Ownship's image exhibited either:

1) HEADING vector which corresponds to gyroheading and is drawn to the edge of the screen, or

2) COURSE vector which represents the course-made-good of ownship and is drawn for the distance ownship will travel in 3 minutes.

TABLE 4. EXPERIMENTAL DESIGN FOR THE MINIEXPERIMENT OF AN/RA DISPLAYS

SUBJECT NUMBER	ORDER OF ADMINISTRATION	DIGITAL		GRAPHIC			PERSPECTIVE
		TKI	TMI	DO	SV	SI	FOV
1	D - G - P	1 2 3	1 2	1 2 3	1 2	1 2	1 2
2	G - P - D	3 1 2	1 2	3 1 2	1 2	2 1	2 1
3	P - D - G	2 3 1	1 2	2 3 1	1 2	1 2	1 2
4	D - G - P	1 2 3	2 1	1 2 3	2 1	2 1	2 1
5	G - P - D	3 1 2	2 1	3 1 2	2 1	1 2	1 2
6	P - D - G	2 3 1	2 1	2 3 1	2 1	2 1	2 1

= each DO is tested with every other SV and SI except for DO-3 which is not tested with SI-2.

Numbers correspond to level numbers shown in Figures 6, 7, and 8 of the text.

TABLE 5. GRAPHIC DISPLAY VARIABLE

	DISPLAY ORIENTATION (DO)	SHIP VECTOR (SV)	SHIP IMAGE (SI)
LEVEL 1	TRACK-UP TRUE MOTION	HEADING	SCALED
LEVEL 2	TRACK-UP RELATIVE MOTION	COURSE	SYMBOLIC
LEVEL 3	HEAD-UP RELATIVE MOTION		

Ownship was shown either as a:

1) SCALED ship's image of actual shape and size scaled to the display range, or

2) SYMBOLICALLY represented as a cross (+) approximately 1/2 inch in diameter.

Pictorial information was the only guidance which pilots received when using the GRAPHIC display. There were 12 possible combinations of the format variable; however, the scaled image with either heading or course vectors were the only levels tested using the head-up, relative motion display. During design of the experiment, it was concluded that an adequate evaluation of symbolic (i.e., cross) versus scaled ship's image could be made with the track-up orientation and that repeating symbolic imagery in the head-up mode was unnecessary. This reduced the number of GRAPHIC displays to be simulated to 10. Each subject was administered the miniexperiment using the 10 displays as indicated in Table 4, the experimental design.

The PERSPECTIVE display was designed to portray the perspective scene as viewed out the forward bridge windows. There was no attempt to reproduce a field of view (FOV) similar to that seen through the windows, but instead, FOV was used as a display variable to promote display effectiveness. It was hypothesized that given a certain vessel size, channel width, and height of eye above the water, only one FOV would be optimal for the pilotage. Table 6 shows the variable levels simulated in the evaluation of the PERSPECTIVE display. When using each PERSPECTIVE display the picture represented either a:

1) 60-degree FOV, 45 foot height of eye and bridge located 200 feet back from the bow; or

2) 90-degree FOV, the same eye location.

TABLE 6. PERSPECTIVE DISPLAY VARIABLE

	FIELD OF VIEW (FOV)
LEVEL 1	60°
LEVEL 2	90°

A 30-degree FOV was examined prior to design of the experiment but was found to be too narrow for observing both boundaries of the channel throughout the bend. The 60-degree and 90-degree levels of the format variable were counterbalanced to accommodate learning. Both were administered to subjects as shown in Table 4, the experimental design.

All parameters of environment, ship hydrodynamics, bridge personnel, bridge arrangement, and display characteristics such as update rate, contrast, resolution, legibility, etc., were kept constant. Scenario characteristics were controlled as much as possible given the subjects' freedom to order rudder and course commands, and vary propeller rpm. Subjects were, however, instructed to stay in the center of the channel and maintain 7 knots through the water as best they could. This ensured scenario consistency.

3.2 SIMULATOR FACILITY

The simulator used in the miniexperiment was developed at and by Eclectech Associates, Inc., to evaluate advanced bridge displays such as the electronic radio aids to navigation display. Previous research by the U.S. Maritime Administration has been conducted at this facility for evaluations of short range collision avoidance displays, maritime radar interrogator/transponder systems, predictor steering displays, and precision navigation displays.

The primary apparatus which was used is a Digital Equipment Corporation GT-44 computer graphics system with PDP-11/40 central processor and VT-11 graphic generation hardware. The VR-17 CRT display is mounted in a free standing pedestal comparable to bridge installed planned position indicator (PPI) systems. It is located on the centerline of the ship and against the forward bulkhead of the bridge just below the gyrocompass repeater. The helm, engine order telegraph, rudder angle indicator, and rpm indicators are installed on a steering console, located to the right of center and also forward as shown in Figure 9. This arrangement is solely for the benefit of the experiment, enabling the subject to monitor all ship control functions with minimum distraction. It is noted that without a visual scene the helmsman does not require a visual range for steering and is able to maintain course using his own console mounted gyro repeater. Figure 10 illustrates the simulator facility, which consists of:

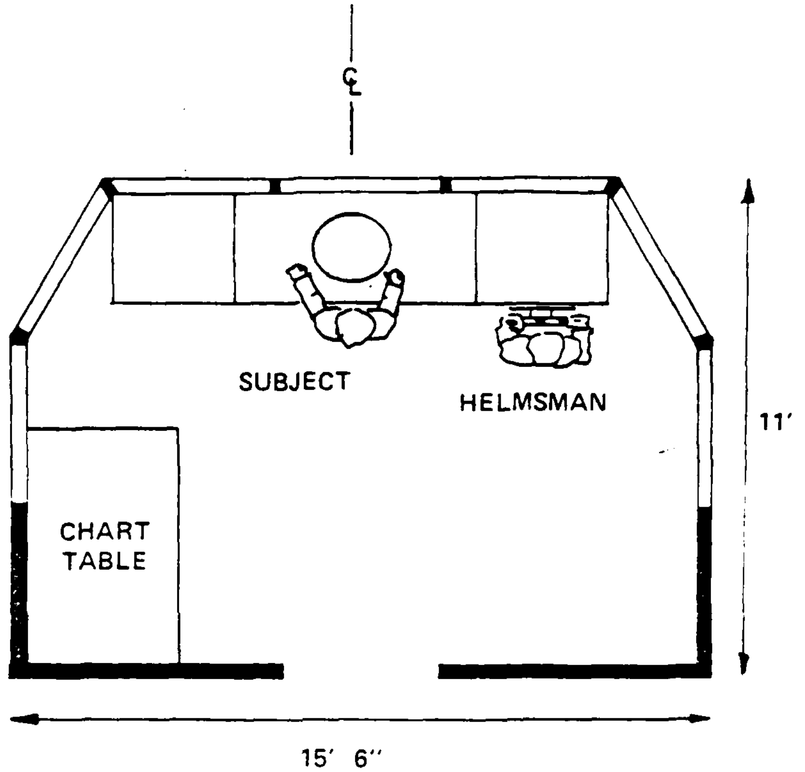


FIGURE 9. SIMULATOR WHEELHOUSE

- wheelhouse
- ship's controls
- ship's indicators
- radio aids to navigation display
- scene projection system
- PDP 11/40 with requisite interface equipment
- data reduction facility

The Wheelhouse. The wheelhouse is a structural mockup approximately 16 feet wide and 11 feet deep. Additional facilities include a chart table with chart stowage. The lighting in the wheelhouse can be varied to night operating conditions.

Ship's Controls. The control mechanisms found in the bridge simulator are tied directly to the PDP 11/40 computer, providing the proper inputs for ship's controls with resultant ship's motion incorporated in the visual image. These control mechanisms include the following:

- a ship's wheel and helm unit
- an engine order telegraph which provides control of the ship's speed both ahead and astern. Propeller rpm is determined by ownship characteristics programmed into the computer

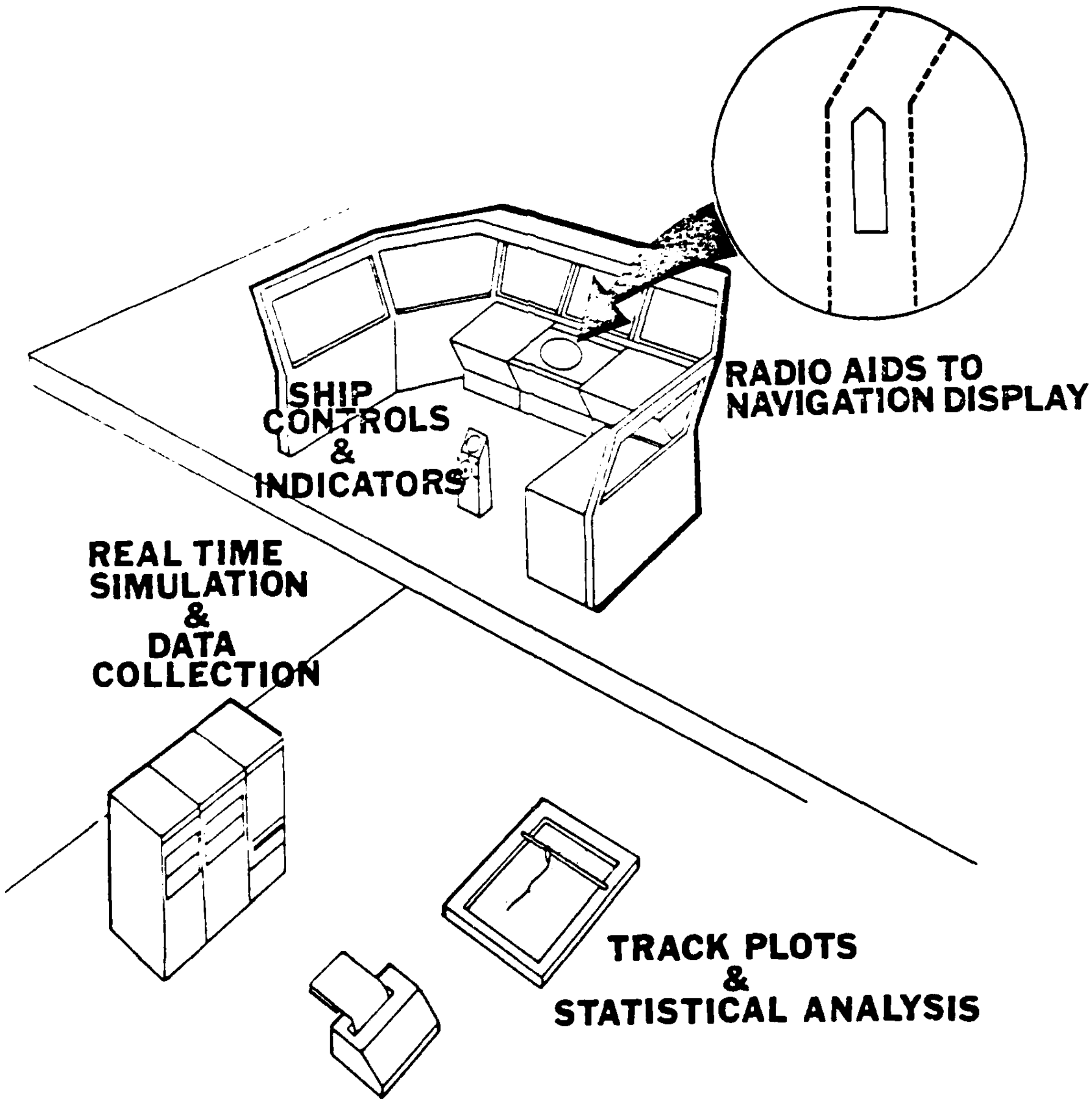


FIGURE 10. SIMULATOR FACILITY

Ship's Indicators. The indicators available to provide information to the pilot include:

- a gyrocompass overhead repeater and console mounted repeater providing indications of ownship's heading as transmitted by the computer
- a shaft rpm indicator that shows the shaft rpm transmitted by the computer
- a rudder angle indicator
- a ship's clock which has been modified to show scenario time

Radio Aids to Navigation Display. The electronic bridge display unit is capable of presenting a variety of information displays to the pilot.

The PDP 11/40 Computer. The PDP 11/40 computer provides dynamic signals for the electronic bridge display or visual system. These signals are modified by the appropriate program to reflect ownship's characteristics including maneuverability, visibility, hydrodynamic influences, and individual scenario conditions.

Data Reduction Facility. The computer facilities are configured to provide supporting data reduction and analysis with a minimum of data manipulation or conversion.

3.3 SCENARIO DEVELOPMENT

The scenario selected for the miniexperiment is shown in Figure 11. It is an abbreviated version of the 1-hour transit which will be simulated in all subsequent radio aids to navigation experiments. The only difference is that in the miniexperiment ownship is initially positioned 0.75 nm from the bend and terminates approximately 0.75 nm beyond it.

The scenario was selected from among those simulated in the Aids to Navigation AN-CAORF experiment. It contained a 35-degree left bend, considered worse case representative of a majority of inland waterways and river bends. Measurement of subject performance from the radio aids to navigation experiment can then be compared to performance in the AN-CAORF and AN-VISUAL runs. This comparison should enable a better appreciation of the time value and safety effectiveness of the navigation displays, particularly after they are simulated in the more realistic noise environment.

Each subject was instructed to keep in the center of the 500 foot wide, 36 foot deep channel. Ownship was a 30,000 dwt tanker, 595 feet LOA, 84 foot beam and 34 foot draft. There was a following current through the first leg at an average of 1 knot. It gradually reduced to 3/4 knot at the bend and became a crosscurrent beyond the bend. Wind was also from astern in the first leg, varying around 30 knots. This force did not diminish but became a crosswind beyond the bend. Because the ship was in ballast, both current and wind had a significant effect on its handling. There was some weathervaning attributable to the crosswind in the second leg.

The scenario channel consisted of a 341-degree (true) first leg and 306-degree (true) second leg. Charts provided to the subject showed ownship's original position, a dead reckoning line, channel boundaries as short dashed lines, and shoal contours outside the channel.

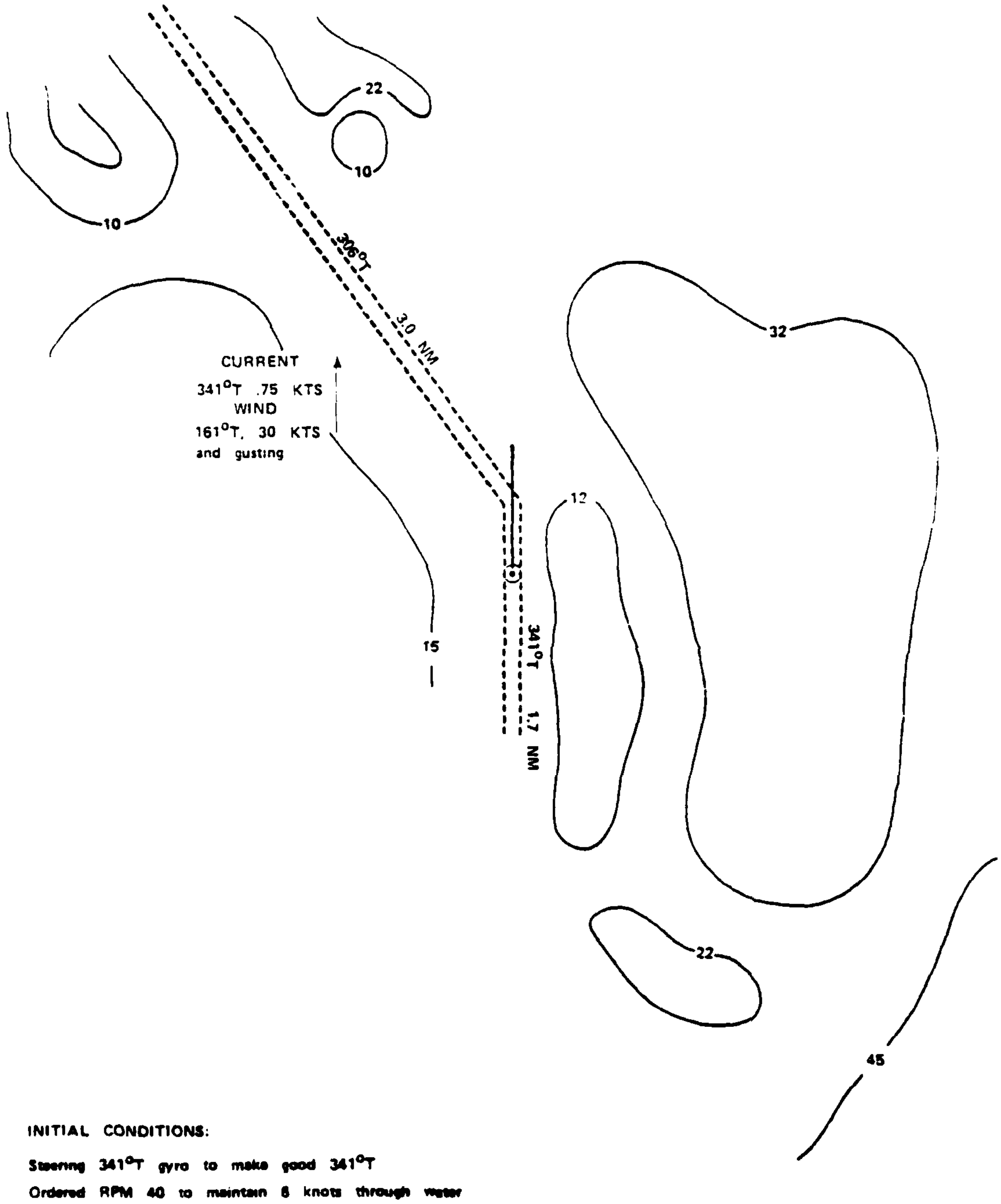


FIGURE 11. SCENARIO WATERWAY

Previous experimental data from comparable scenarios[4] reveal that subjects will enter the turn with little crosstrack variation but will be at unique distances into the bend as a result of personal preference. Because of individual maneuvering strategies as well as resultant performance differences, subjects are expected to exit the turns with greater crosstrack variance but with a crosstrack mean close to the centerline. Given optimal information for turnmaking and compliance with requirements to keep to the center of the channel for trackkeeping, it should be possible to achieve both a low variance (small standard deviation) and mean track on the centerline for the entire subject group. Performance was therefore measured as a function of trackkeeping variance and mean track-made-good. Subjects were also scored on how they controlled speed and their use of rudder to negotiate the turn.

3.4 SUBJECT SELECTION

Six individuals with pilotage experience acted as subjects for the miniexperiment. Each subject used all 18 variations of the DIGITAL, GRAPHIC, and PERSPECTIVE displays. Runs were completed in less than 6 hours allowing time between runs for critique of the previous display, instructions for the next display and questions. The instruction sheets are presented in Appendix A. All subjects selected were familiar with the response characteristics of a 30,000 dwt tanker. Nevertheless, they were given opportunity to maneuver the simulated ship prior to the first run.

All subject comments both during and after each run were recorded and analyzed (see Section 4.0). Subject performance was also observed for signs of anxiety, stress, fatigue, etc., as well as for any particular difficulties and compliance with accepted bridge watch procedures. In general, all subjects responded well to the tasks required and their performance was considered valid to accomplish the objectives of the miniexperiment.

3.5 ADMINISTRATION

Administration of the display variable was designed to investigate within subject effects, thus minimizing individual differences and encouraging a higher probability of finding significance than would be experienced by between subject effects. This, of course, meant a large number of scenario repetitions for each subject with the resultant possibility of introducing order effect (e.g., learning, anticipation, boredom caused solely by repetition). For this reason, a test for order effect was conducted on all data.

Table 7 displays the actual subject assignments which were derived from the experimental design (see Table 4). Note that the order of administration of all variables is counterbalanced to compensate for learning. Abbreviations (e.g., TKI, TMI, DO, SV, SI, and FOV) are used to identify each variable and numbers (e.g., 1, 2, or 3) identify each level. These are described in Tables 3, 5, and 6.

Subject assignments defines the order in which all variables were administered. For example, subject 1 first used the DIGITAL display which included crosstrack distance and crosstrack speed only (TKI-1), turn rate, recommended turn rate, and distance to leadline (TMI-1). For his second run he used the DIGITAL display again,

[4] Eclectech Associates, Inc., AN-CAORF Preliminary Observations, United States Coast Guard, December 1979.

with the same trackkeeping information (TKI-1) but with time to leadline instead of distance to leadline (TMI-2). The variables for his other runs and the other subjects' runs can similarly be determined from Table 7.

In summary, the experimental design permitted the best mix of administration options to perform the miniexperiment inexpensively and expediently yet retaining the necessary requirements to ensure statistical validity and confidence.

TABLE 7. SUBJECT ASSIGNMENTS

ORDER OF ADMINISTRATION	SUBJECT NUMBER 1	2	3	4	5	6
1	1-1*	3-1-1**	1***	3-2-1	1-2	2
2	1-2	3-2-1	2	3-1-1	1-1	1
3	2-1	1-1-2	2-1	1-2-1	2-2	2-2
4	2-2	1-1-1	2-2	1-2-2	2-1	2-1
5	3-1	1-2-2	3-1	1-1-1	3-2	3-2
6	3-2	1-2-1	3-2	1-1-2	3-1	3-1
7	1-1-1	2-1-2	1-1	2-2-1	1-2-2	1-2
8	1-1-2	2-1-1	1-2	2-2-2	1-2-1	1-1
9	1-2-1	2-2-2	2-1-1	2-1-1	1-1-2	2-2-2
10	1-2-2	2-2-1	2-1-2	2-1-2	1-1-1	2-2-1
11	2-1-1	2	2-2-1	1	2-2-2	2-1-2
12	2-1-2	1	2-2-2	2	2-2-1	2-1-1
13	2-2-1	3-1	3-1-1	3-2	2-1-2	3-2-1
14	2-2-2	3-2	3-2-1	3-1	2-1-1	3-1-1
15	3-1-1	1-1	1-1-1	1-2	3-2-1	1-2-2
16	3-2-2	1-2	1-1-2	1-1	3-1-1	1-2-1
17	1	2-1	1-2-1	2-2	2	1-1-2
18	2	2-2	1-2-2	2-1	1	1-1-1

*2 digit number indicates levels of TKI-TMI for DIGITAL display
**3 digit number indicates levels of DO-SV-SI for GRAPHIC display
***1 digit number indicates level of FOV for PERSPECTIVE display

Section 4
DATA COLLECTION AND ANALYSIS

Data on the trackkeeping and shiphandling performance of subjects was recorded automatically every 475 feet along the channel by the facility computer for subsequent statistical analysis and graphic illustration. Observed data and subject comments were written by the observer during the simulations.

The analysis was conducted in two stages. The first stage provided a preliminary overview of performance by combining observed data with crosstrack measures at the entrance and exit to the turn and rudder actuations required to accomplish the turn. This behavioral analysis is described in Section 4.1. The second stage of analysis was developed as an analytic technique for the evaluation of trackkeeping to be used in the AN-CAORF and AN-VISUAL experiments. It was used in the radio aids to navigation experiments both because it aided in the interpretation of statistical measures and because it enabled a direct comparison of performance between all other aids to navigation (AN) experiments.

4.1 BEHAVIORAL ANALYSIS

Subject perceptions of each format were elicited by asking them to compare variables within each DIGITAL, GRAPHIC, and PERSPECTIVE display. The intent of this survey was to establish preferred displays in case several were shown to promote comparable performance and were similar enough in design not to warrant re-evaluation. These opinions were not statistically tested due to the small sample size. They were, however, quantified and are presented in consideration of the overall conclusions.

A qualification of trackkeeping was performed by statistically analyzing crosstrack deviation (mean distance in feet from the centerline) and crosstrack variability (one standard deviation of subjects about the mean) at two different points in the channel, 0.25 nm before the bend and 0.25 after the bend. This analysis was designed to indicate trackkeeping ability at the entrance to the bend and again how well the subject recovered from the turn. Interpretation of trackkeeping performance up to the entrance, through the bend, and after the recovery was the subject of the second stage of analysis.

Two rudder actuations, initial rudder and check rudder, were analyzed. Also the manner in which subsequent rudders were applied was addressed. For example, some subjects selected an initial turn rudder and maintained it throughout the maneuver. Others intentionally selected a large rudder, then gradually or in discrete steps reduced it through the maneuver. Still other subjects initiated the swing with a given rudder, but found it was insufficient to satisfactorally complete the maneuver. These subjects used additional rudder, often too late, to recover on the new leg centerline. Although the first two methods describe a preferential and usually satisfactory behavior, the latter suggests an inadequate estimation of rudder requirements and an otherwise deficient behavior. For these reasons, not only was the amount of initial rudder considered in the behavioral analysis, but also the ship's location, heading, subsequent rudders, and final location in the new leg.

Because all rudder angles were administered in discrete steps (e.g., 5, 10, 15, 20 degrees) and because larger rudder angles could always accomplish the turn while

some of the smaller rudder angles might not, a normal distribution of rudder applications could not be assumed. This necessitated the selection of a non-parametric statistical measure for the overall rudder utilization analysis. The Wilcoxon signed rank test was employed to enable paired comparisons of all runs for each display by ranking differences instead of absolute values. For the analysis of trackkeeping into and out of the bend, the t-statistic and difference of variability (F test) were used.

All reported or implied significance documented in the behavioral analysis is at the 90 percent confidence level.

4.2 TRACKKEEPING ANALYSIS

To augment the behavioral analysis and aid in interpreting the trackkeeping performance statistic, track plots showing the group mean track and twice the crosstrack standard deviation were constructed. These plots were drawn for approximately 0.25 nautical miles either side of the bend. The track lines represented were drawn from the center of gravity (CG) of ownship. In essence, the shaded envelope typically contains all individual track plots for the selected display variable and, assuming that the subject group was a representative sample of the pilot population, would represent 95 percent of all ship tracks made under similar operating conditions. The trackkeeping analysis is presented in Section 5. All combined track plots derived as a result of the experiment are contained in Appendix D.

Section 5
RESULTS AND CONCLUSIONS

In light of the measures and statistical analyses performed, the results of the miniexperiment suggest that all the displays evaluated could promote a safe transit of the waterway under conditions in which perfect position information (i.e., no system error) was portrayed on the display. Of the 126 total runs which were conducted using the radio aids to navigation displays, there were no major excursions from the channel.

Two DIGITAL runs with HEADING TO STEER information were excluded from the analysis because the display presented erroneous information to a subject. The cause was traced to an inadvertent programming error introduced during the presimulation phase of the experiment; however, none of the other variables and only one subject's runs were affected. Removal of two runs from the data pool (n=34) did not significantly alter the experimental results.

In general, all valid runs were completed without major difficulty and with no obvious detrimental effect on traditional pilotage behavior. Subjects, however, were noted to digress from their normal discrete rudder commands (e.g., 5 degrees, 10 degrees, 15 degrees, 20 degrees) when using the digital display. They ordered 6, 7, and 8 degrees, etc. This behavior resulted from attempts to match "actual" turn rate with "recommended" turn rate. It can only be speculated that this traditionally uncharacteristic behavior would not be detrimental to real world pilotage. The results were not specifically analyzed in the miniexperiment, but its close observation and scrutiny is recommended for all subsequent simulations.

Other unique findings and recommendations of the miniexperiment are presented in the following comparisons of learning effect, between DIGITAL, GRAPHIC and PERSPECTIVE concepts, and between individual display variables.

5.1 ORDER EFFECT AND PERFORMANCE INDICATORS

Due to time constraints, an analysis of individual subject learning effect was relinquished in favor of comparing all subjects' first, middle, and final runs regardless of which display they had used. Since all display variables were counterbalanced in the experimental design to negate order effect, it is assumed that any difference in performance between the first, middle and final runs (see Figure 12) could be attributed to the subjects learning the waterway, ship characteristics, simulation anomalies, etc. A comparison of subject performance between the first, middle and final runs demonstrates how the waterway might be transited once subjects had achieved high proficiency.

The exact period of the greatest learning increase was not determined; however, the referenced tables and figures show that much of the proficiency enhancement was evident by the middle run. This finding is supported by previous CAORF

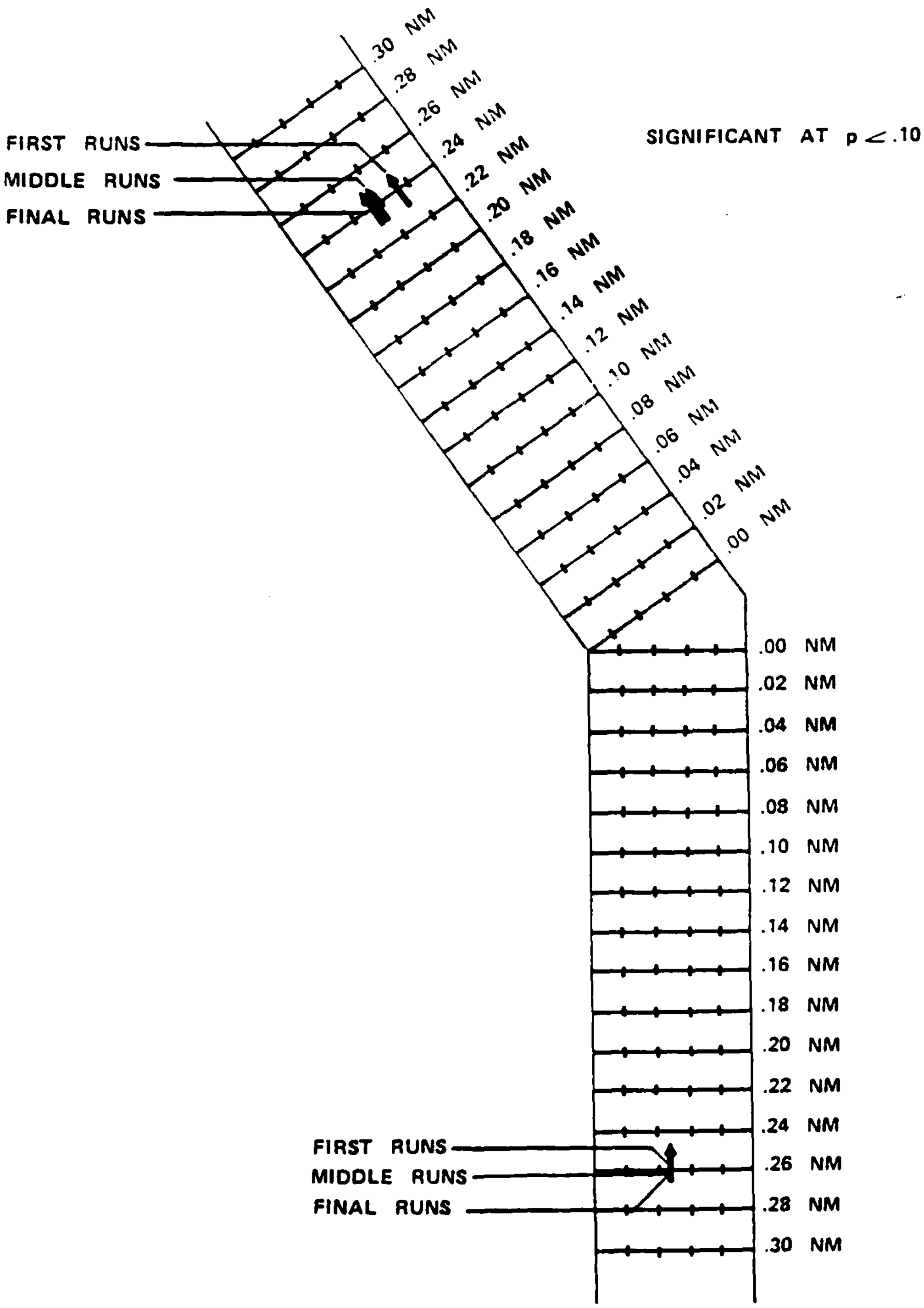


FIGURE 12. TRACKKEEPING BY ORDER OF RUN 0.25 NM BEFORE AND BEYOND BEND

research[5,6] which show pilots' adaptation to relatively unfamiliar bridge display systems to be rapid; usually within the first, or if the first is brief, second exposure.

Using the above rationale, it can be hypothesized that for the given simulation conditions, a highly effective display would be one which promotes pilotage performance most closely resembling that of the entire group's final, most proficient run. This is most valid in an experiment such as the radio aids miniexperiment where every subject experiences each display variable and the order of presentation is counterbalanced within the subject group. It is with this premise and a knowledge of what constitutes effective, safe shiphandling practice that the following analytic discussion is promulgated.

5.1.1 Trackkeeping Statistic

The preliminary measure of trackkeeping in the miniexperiment was crosstrack distance from the centerline (right or left) at a point exactly 0.25 nm before the bend and 0.25 nm beyond the bend. Since ownship started on the centerline at a point 0.75 nm from the bend, the subject had 0.50 nm mile to demonstrate his initial trackkeeping ability. Given the scenario conditions and the fact that ownship was originally well aligned on track, it was not difficult to keep to the center of the channel up to the bend.

There was no significant difference in subjects' ability to keep on the centerline of the first leg regardless of the display they used or when they made the transit. There were, however, differences in trackkeeping consistency (i.e., variability) among the subject groups as a function of which display was used. Ideally, an effective display would promote small variability, particularly with the trackkeeping task where all subjects had a common goal.

Table B-1 in Appendix B shows the group mean crosstrack distance and group crosstrack variability for the first, middle and final runs. Both mean crosstrack distance and variability are low at 0.25 nm before the bend indicating the relative ease with which the approach leg was transited even during the subjects' first runs. These mean crosstrack distances in the approach leg are shown at the bottom of Figure 12.

It is suggested that the miniexperiment did not provide an adequate challenge to the trackkeeping requirements of a straight leg and therefore did not contribute conclusive evidence on the displays' effectiveness for this task. It is therefore recommended that subsequent display evaluations contain a longer approach leg, with possibilities for perturbing the track-made-good either through crosscurrents, crosswinds or required evasive maneuvers.

The trackkeeping measure in the exit leg which occurred at 0.25 nm beyond level was selected to represent how well subjects recovered from the turn and realigned

---

[5] CAORF Research Staff, Simulator Evaluation of Predictor Steering, Short Range Collision Avoidance and Navigation Displays, Report Number CAORF 30-7913-01, National Maritime Research Center, Kings Point, New York, November 1979.

[6] CAORF Research Staff, Valdez Operational Exercises, National Maritime Research Center, Kings Point, New York, August 18, 1977.

on the new centerline. This 0.25 nm distance was well beyond the point at which check rudder was required; and if an appropriate maneuver had been executed, ownship would have been steadied up on its new course.

Table B-1 shows significant differences in returning to the centerline during the first runs but not during the middle and final runs. This is graphically portrayed at the top of Figure 12. The mean track of the first runs was 107 feet to the right of the centerline with a group variability of 110 feet about the mean. Considering the 85' foot beam of the simulated ship, it can be calculated that on their first run approximately 84 percent of all subjects ($1\sigma + \frac{1 - 1\sigma}{2}$) aligned in the new leg with more than 50 feet between their ship hull and the right channel boundary. In light of the goal to align on the channel centerline, this result may not be highly commendable, but it does indicate that even the first runs were conducted well within a margin of safety. In both the middle and final runs, subjects significantly ($p < 0.10$) improved both this mean track-made-good and track variance.

This significant improvement in recovering from the turn and aligning on the new leg as a result of learning suggests that the crosstrack distance measure at 0.25 nm beyond the level is a highly sensitive measure of pilotage performance. While the "before the bend trackkeeping measure" only provided information on how well ship's course was maintained, the "after the bend trackkeeping measure" provided a clue into how well the turn maneuver was executed and/or how well the ship exited and steadied-up after the turn. To determine which of these factors contributed most to the second leg trackkeeping performance, an analysis of rudder utilization through the turn was required.

5.1.2 Turning Statistic

Initial rudder for maneuvering around a bend is characterized by (1) magnitude or amount of rudder in degrees; (2) where it is applied in relation to the bend, ship's crosstrack position in the channel, and ship's course error (difference between ship's course and channel alignment); and (3) duration of time it is applied.

Once initial rudder is applied and the ship begins to swing, subsequent increased or decreased rudder may be applied to modify the swing. Pilot preferences tend to be inconsistent, however, since some prefer to apply a gradually increasing rudder with resultant gradually increasing swing into the turn while others prefer a large rudder to start the swing quickly using subsequent decreasing rudder to control and slow the swing through the turn. Most pilots agree that sharp bends in a narrow channel do not afford the luxury of the gradual rudder approach and are best accomplished with one well selected rudder through the entire turn.

This latter requirement was considered during the selection of the radio aids to navigation scenario because an effective display would enable subjects to select the most appropriate rudder the first time. If this was possible, all selections of gradually increasing or gradually decreasing rudders could also be accommodated.

In light of the above rationale, the incidence of increasing initial rudder was employed as a measure of how well the displays enabled subjects to determine the steering requirements. A decrease of initial rudder in the bend was considered acceptable to the pilotage, but an increase in initial rudder implied that the original judgment was deficient and that sufficient turn rate had not been achieved to complete the turn to the subjects' expectations.

The incidence of increasing rudder in the bend is measured by the percent of those individuals in the group who increased their initial rudder at any time in the bend. Where a statistically significant difference is indicated, that display variable with the lowest percent could be expected to have promoted a more accurate selection of initial rudder angle. Table B-1 (line 11) shows no change in the incidence of increasing initial rudder angle through the bend as a function of learning. Only half of all the subjects were satisfied with their initially selected rudder at the beginning of the experiment, throughout it, and at the end. As shown in later sections, however, certain display variables may have promoted this behavior even through to the final run.

The application of check rudder proved to be the most sensitive measure of turning performance and consequently of display effectiveness. As with initial rudder, magnitude, ship position, course error and duration of rudders play important parts in interpreting appropriateness of the check rudder. Table B-1 compares both initial and check rudder applications between first, middle, and final runs. There are not statistically significant differences in any of the initial rudder measures (lines 3 thru 6) except for variability (lines 15 and 17). In essence, initial rudders were appropriately applied in the subjects' first runs and there was little room left for improvement by the middle and final runs.

The bottom of Figure 13 shows measured difference which indicate that the middle and final runs averaged a 5-degree less initial rudder than the first runs. This rudder was also applied earlier ahead of the bend. The reader is cautioned however, that these measures are not statistically different at the $p < 0.10$ level of confidence and are presented only to illustrate a trend.

The check rudders however are statistically different as shown at the top of Figure 13. Table B-1 (lines 7 through 10) shows a significantly ($p < 0.10$) higher course error (10.70 degrees), lower but left side of the centerline crosstrack distance (32 feet), and closer to the bend (0.075 nm) when the check rudder was applied. Magnitude of check rudder (15 degrees) is consistent in all runs.

The standard deviation of measures (Table B-1) shows a significantly ($p < 0.10$) larger variability for course error (13.18 degrees) and a lower variability for distance from the bend (0.019 nm). By the time the subjects had reached their final runs, they were using the same amount of check rudder but applying it significantly earlier and in a more appropriate location to bring them on the new centerline.

The appreciation of the finding is important to the evaluation of display design because it implies that all the display variables probably exhibited similar initial rudder behaviors, but only as a result of the scenario limitations. Check rudder behavior, however, was totally dependent upon pilot judgment and his availability and interpretation of navigation information. As such, check rudder behavior, its timeliness and accuracy, is considered a major indicator of the overall turnmaking performance.

5.1.3 Observations

A comparison between early run observations and those at the final runs indicates that all subjects performed confident and assertive pilotage throughout the experiment. Three of the subjects had previously participated in similar type display evaluations and were initially less apprehensive about what would be expected of

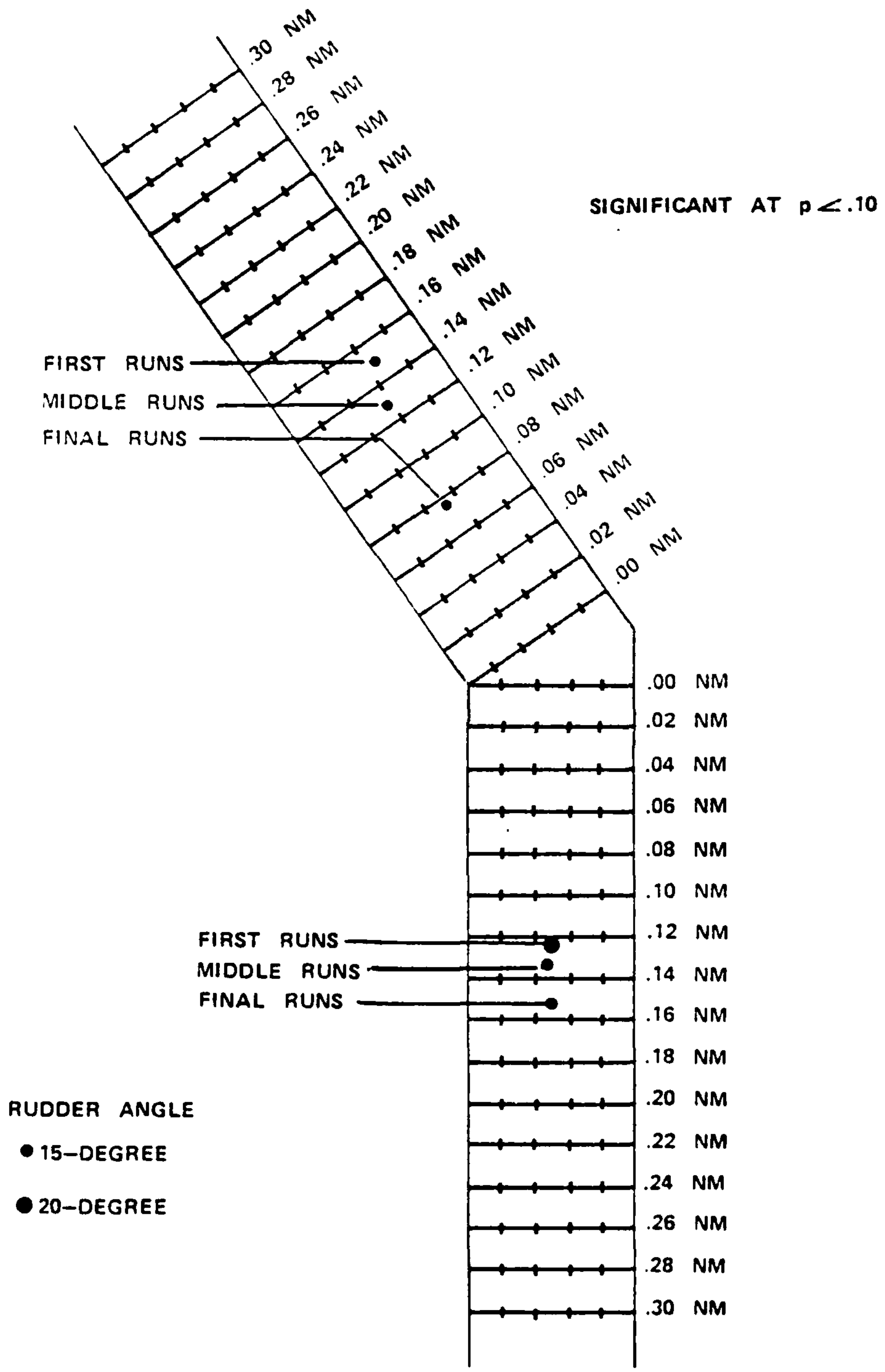


FIGURE 13. ORDER OF RUN — INITIAL RUDDER AND CHECK RUDDER

them than the others were. None of the subjects, however, had seen these particular displays nor had they operated the simulator with the 30,000 dwt tanker characteristics. All subjects considered the bridge arrangement, helmsman performance, and equipment adequate for the pilotage although they stated that the margin of transit safety would depend upon visibility conditions and overall navigation system accuracy. The subjects indicated that the channel was realistic and many asked where it was located.

Subjects issued course commands in the straight legs and rudder commands for initial and check rudders. Once on track in the exit leg and at least partially steadied-up, course commands were again used. All subjects employed this practice with noticeable consistency from the first through the final runs. There was, however, the obvious tendency to permit the helmsman greater latitude in steadying up himself once the pilot was confident of the helmsman's proficiency.

The miniexperiment made no attempt to correlate when course commands were issued and when rudder commands were issued with regard to the displays in use. Because of increased maneuvering diversity in the full-length scenario of the subsequent experiments, it is recommended that course commands and rudder commands be recorded separately and their incidence compared as part of the analysis.

The operation and monitoring of bridge equipment (e.g., engine order telegraph, gyro repeater, rpm indicator, rudder angle indicator) posed no initial or subsequent problem to the subjects. Prior to each subject's first run, a complete familiarization with the bridge, bridge equipment, and arrangement was conducted by the test director. A checklist which ensured compliance with all familiarization requirements is presented in Appendix C.

In their first runs, subjects spent considerable time checking the chart to familiarize themselves with the course requirements and particulars of the waterway. By their last runs, this information was well known. Initially, subjects stood in front of the display occasionally walking to the chart table and around the wheelhouse as though attempting to maintain a lookout. By the end of the experiment all but one pilot had accepted the offer of a high stool and remained seated in front of the display for the duration of the run.

At the end of each run, subjects were asked to critique the run and display they had just used. There were no comments by any of the subjects which reflected their learning experience between the beginning and end of the experiment. There were, of course, opinions regarding the learning of each display concept or variable as it was presented. These comments are discussed in the later sections which compare the display designs.

In general, there were no observed signs of fatigue or boredom. Most subjects found the variety of displays and display variables continuously challenging and thought the scenario was particularly difficult, even from the beginning. It is recommended that for the subsequent full-length scenarios, subjects be queried as to how well they thought they did in each run. This technique was successfully employed in the Advanced Bridge Display Evaluation at CAORF[7] by using a brief

[7]The Computer Aided Operations Research Facility at Kings Point, New York owned and operated by the U. S. Department of Commerce, Maritime Administration.

structured questionnaire which elicited relative comparisons of each run with the previous run. The questions were brief, did not burden the subject, and resulted in an objective appraisal of each subject's perception of his own performance and of the display.

5.2 EFFECTIVENESS OF DISPLAY CONCEPTS

The intent of the miniexperiment was to select those variables from among three DIGITAL, GRAPHIC, and PERSPECTIVE display concepts which are most effective, and thus worthy of the full-length simulator evaluation. As such, the experimental design was not structured to accommodate a powerful statistical comparison between display concepts. Nevertheless, it was possible to average the measures of each of the display concepts, and using the t-statistic determine which if any produced significantly different results at the $p < 0.10$ confidence level. This analysis produced the greatest single contribution of the miniexperiment. It signified a need to re-mechanize the DIGITAL display turn initiation point to make the DIGITAL display shiphandling requirements more compatible with those of the GRAPHIC and PERSPECTIVE displays.

5.2.1 Trackkeeping Statistic

Table B-2 compares the trackkeeping measures between each display concept. Although there is no difference between displays in crosstrack distance on the approach leg, Table B-2 shows significantly less crosstrack variability among the subject group when the DIGITAL display was used prior to the time of initial turn rudder.

In the exit leg, 0.25 nm beyond the bend, ownship was still significantly to the left of the centerline when the DIGITAL display was used, but to the right of centerline when the GRAPHIC and PERSPECTIVE displays were used. These trackkeeping measures are illustrated in Figure 14. Immediately a difference in pilotage performance is suspected.

5.2.2 Turning Statistic

The analysis of initial rudder (Table B-2 and Figures D-1, D-2 and D-3 of Appendix D) show a significant difference between DIGITAL and the other displays in both the magnitude and ownship's distance from the bend when the rudder was applied. This is illustrated at the bottom of Figure 15. This difference can be directly attributed to the preprogrammed operation of the DIGITAL display, which had been calculated for a 10-degree standard rudder and a haul point (i.e., leadline) at approximately 0.20 nm. At the time this calculation was made, it was hypothesized that subjects would use standard rudder to negotiate the turn. As a result of the miniexperiment and the experience with GRAPHIC and PERSPECTIVE displays, it is recommended that the DIGITAL display program be modified to calculate a 20-degree turn rudder initiating at approximately 0.10 nm from the bend or allow the pilot to select the leadline position. This change will bring all shiphandling requirements of the simulation more in line with one another, and will permit a valid statistical comparison between display concepts in the subsequent experiments.

The analysis of check rudder (Table B-2) reinforces the finding that with the DIGITAL display, ownship made extremely shallow turns, perhaps passing across or

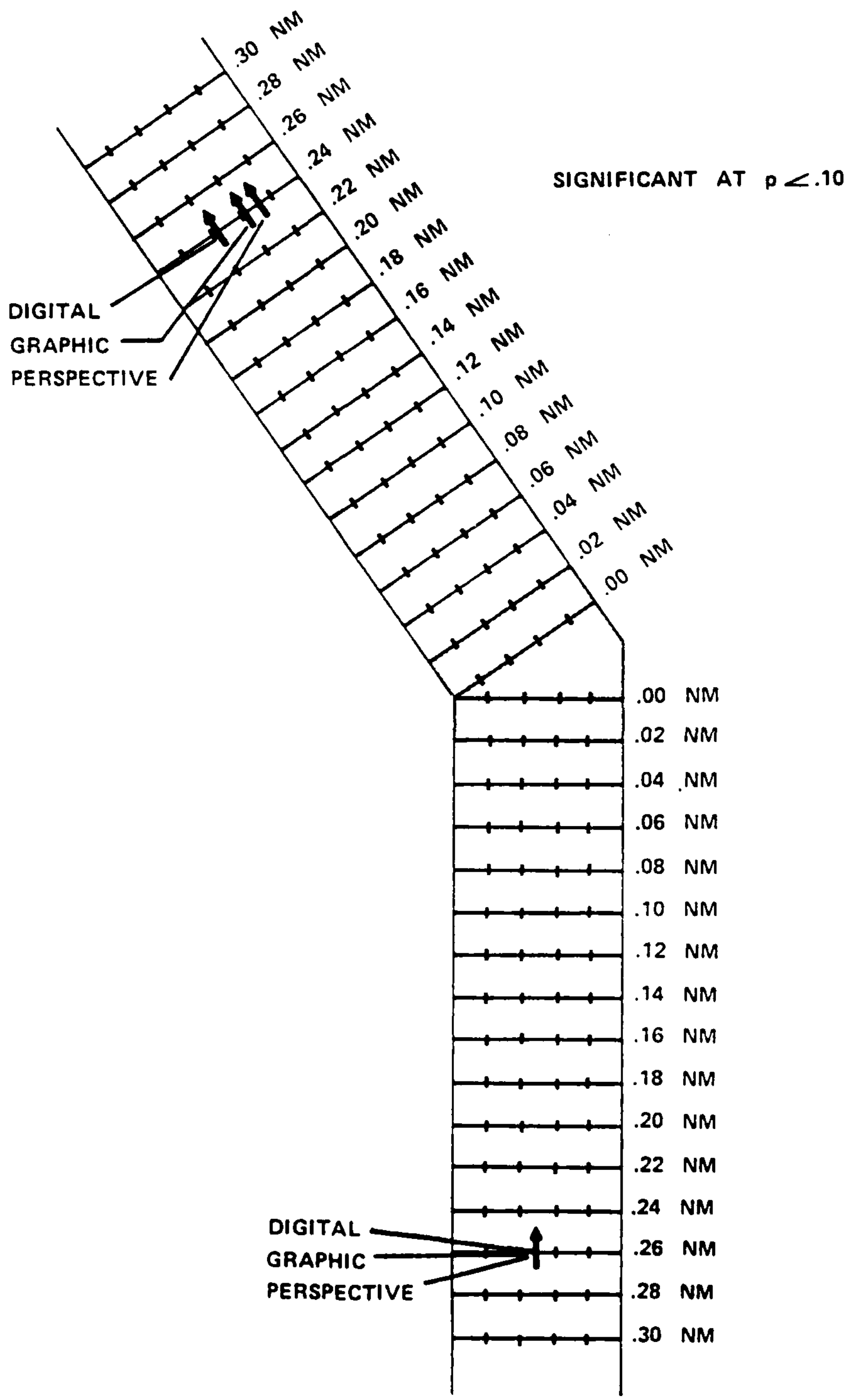


FIGURE 14. TRACKKEEPING BY DISPLAY CONCEPT 0.25 NM BEFORE AND BEYOND BEND

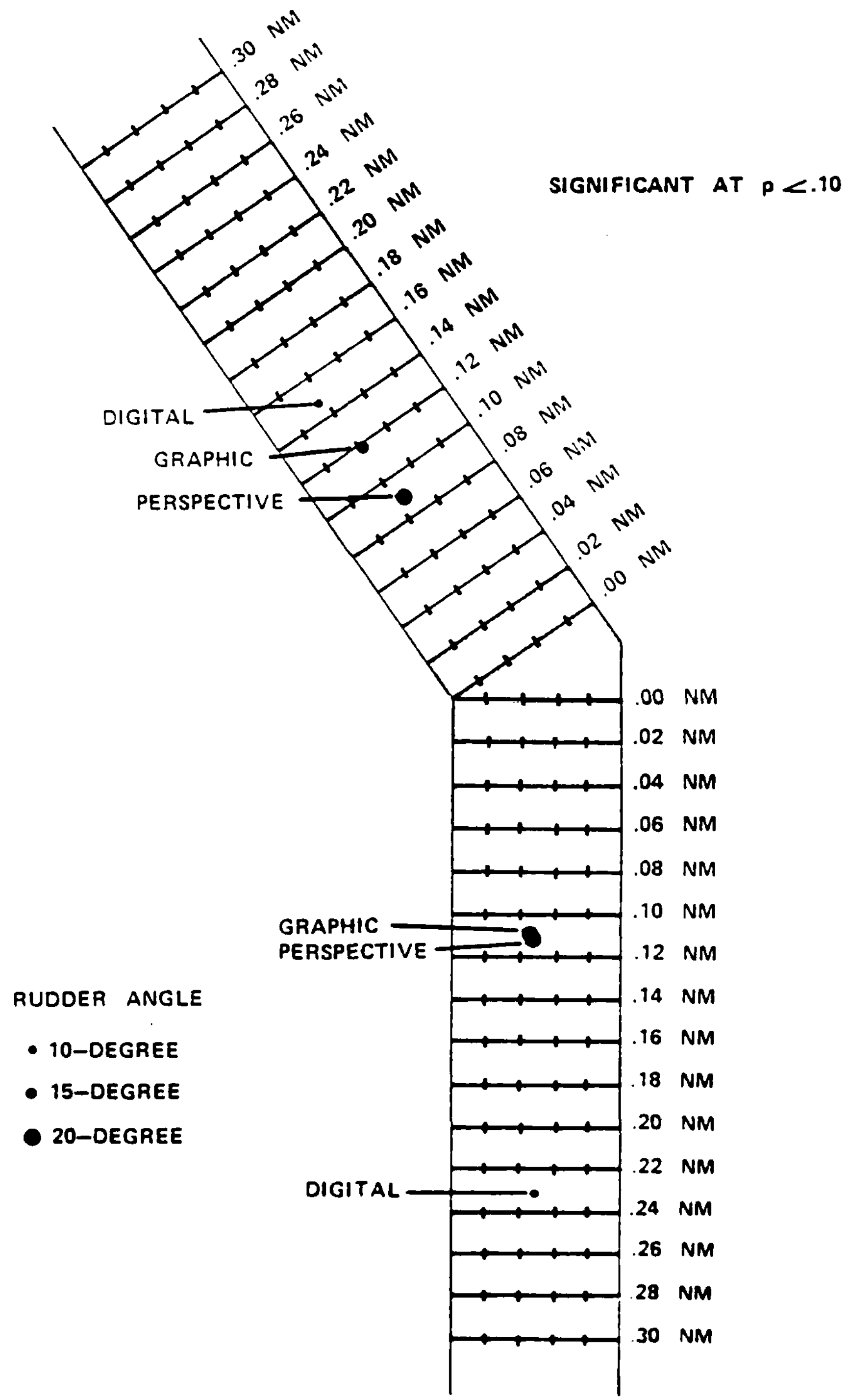


FIGURE 15. DISPLAY CONCEPT — INITIAL RUDDER AND CHECK RUDDER

coming needlessly close to the point of the bend. This is implied by the location of ownship, 50 feet to left of the channel centerline and 0.162 nm beyond the bend at the time the check rudder was applied (see Figure 15). An apparent high crosstrack variability in the bend, which is shown in Figure D-1, is not revealed in the statistic.

At the same time, a comparison between the PERSPECTIVE display and the other two concepts shows a significant difference in the amount of course error (high to the right) and distance from the bend (low to the left) when the PERSPECTIVE check rudder was applied. Table B-2 also shows a high check rudder variability among the group when they used the PERSPECTIVE display. Finally, there was a significantly high incidence (83 percent) of increasing the initial rudder through the bend when PERSPECTIVE was used.

All of these measures imply a high degree of inconsistency among subjects when they used the PERSPECTIVE display. The significantly different rudder and crosstrack measures signify a very high turn rate through the turn, with an 82-foot overshoot at the exit leg centerline. This conclusion is supported by the 5-degree larger check rudder (although not statistically significant) which was applied and the 83 percent probability that the initial rudder was increased above 20 degrees in the turn. The result is not a particularly commendable performance in light of the significantly better GRAPHIC measures; but it does indicate that pilotage is possible with a PERSPECTIVE type display and the concept should continue to be evaluated.

5.2.3 Observation

Overall, the majority of subjects preferred the GRAPHIC representation of navigation information because they could easily interpret all spatial relationships of ownship within the defined waterway. The subjects felt that a shorter range scale than that used in the miniexperiment would be more desirable and implied that had range been selectable they would have switched to a 0.50 or 0.75 mile scale. As a result, a 0.75 range will be recommended for use during the subsequent RA-1 experiment. Presentation of a 0.50 mile scale is considered inadequate for the 3-minute track prediction vector and may not provide a sufficient "view" ahead on the true motion display for a ship traveling at 8 to 10 knots. Arbitrary selection of range scales by the subjects is also unacceptable since it would introduce an additional experimental variable.

Several subjects felt that the overall display would be more effective if both graphic and digital information were combined. This, of course, is an acknowledged alternative to the display, but is intentionally being omitted in the study so the cost implications of each concept can be isolated and evaluated individually.

Since most of the subjects never used a digital display system to navigate a ship and the concept of quantitative interpretation was somewhat foreign to their pilotage task, it is not surprising that they initially expressed the most dissatisfaction with the DIGITAL display.

Once they were confident of the concept's reliability and their own ability to relate its information to the pilotage (usually 2 to 3 runs) most of the subjects grew comfortable using it. All said, however, they would be skeptical of its application in the real world both because of potential system inaccuracies and of possible difficulties in user interpretation. Again, subjects believed the information was not sufficiently comprehensive on a stand-alone basis and should be combined with a GRAPHIC or PERSPECTIVE display.

In general, the only criticisms subjects' had for the PERSPECTIVE display was its inability to (1) show forward velocity, (2) show position or swing of the stern, and (3) accurately portray when ownship was in the center of the channel. As far as subject opinions were concerned, there is no doubt but that the GRAPHIC display was most preferred during the simulation with PERSPECTIVE and DIGITIAL following in order.

5.3 EFFECTIVENESS OF DIGITAL DISPLAY VARIABLES

Measures of comparison between the six DIGITAL displays which were evaluated are presented in Table B-3. The statistical analysis of measures was performed between independent variables and are presented in Table B-4 for steering cues (course error or heading to steer), and Table B-5 for turning cues (distance to leadline or time to leadline). The resultant trackkeeping performance is illustrated in Figures D-4 through D-14 of Appendix D.

A review of the data shows that all DIGITAL displays resulted in highly variable turning performance, considerably inside th` bend as previously discussed in Section 5.2.2. There appears to be a consistency among DIGITAL displays both for crosstrack distance and rudder utilization (see Figure 16). Trackkeeping average in the approach leg (0.25 nm before the bend) is on the centerline almost to the point of absurdity (i.e., 7 feet left to 4 feet right of center). All exit leg average tracks are to the left of center but no more than a ship width. Crosstrack variability is large in the exit leg.

Initial rudders are all identical as are distances from the bend when initial rudder was applied. These similarities were expected since it was the display program which cued each subject when the begin the turn. All course errors and crosstrack distance were low with the exception of the "cross error, distance to lead" display. Here ownship was 25 feet to the left of center, but was continuing left with a 3.35 degree course error. The cause of this behavior will be explained in the comparison of variables.

The analysis of check rudder as shown in Table B-3 is more complex because it involves three dependent measures all varying as a function of where (or when) the check rudder was applied.

For example, if check rudder were applied when either:

a. course error was low to the <u>right</u> and crosstrack distance high to the <u>left</u>, or

b. course error was low to the <u>left</u> and crosstrack distance was high to the <u>right</u>

the check rudder would have been applied too early. However, if check rudder were applied when either:

a. course error was low to the <u>right</u> and crosstrack distance was high to the <u>right</u>

b. course error was low to the <u>left</u> and crosstrack distance was high to the <u>left</u>

c. course error was high to the <u>right</u> and crosstrack distance was from low <u>left</u> to high <u>right</u>

d. course error was high to the <u>left</u> and cross track distance was from low <u>right</u> to high <u>left</u>

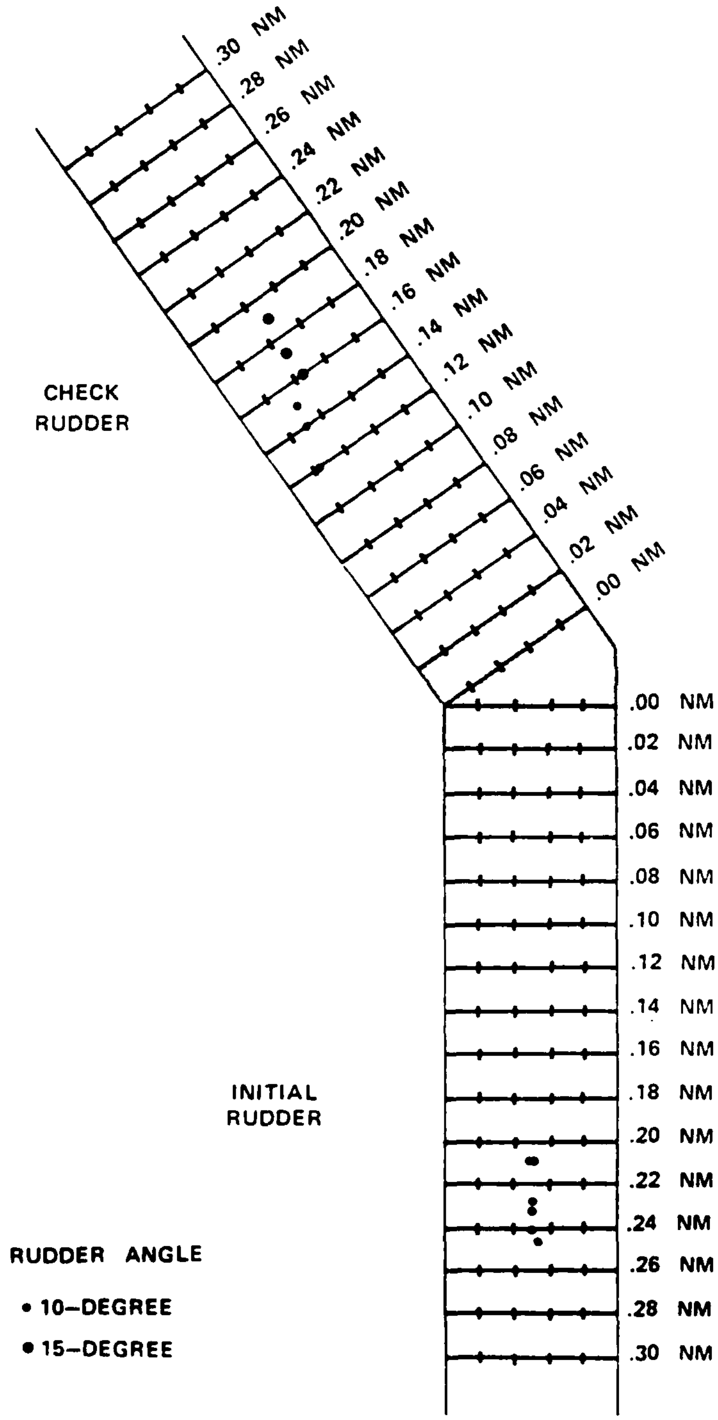


FIGURE 16. DIGITAL DISPLAY – INITIAL RUDDER AND CHECK RUDDER

the check rudder would have been applied too late. Fortunately, distance from the bend at which the check rudder was applied was relatively consistent for all DIGITAL displays, otherwise the analysis of appropriate check rudder would have been further complicated.

Using the above criteria and referring to Table B-3 (lines 8 and 9), it is shown that all of the check rudders were appropriately applied. Each exhibited a high right course error and high left crosstrack distance, low left course error and low left crosstrack distance, or low right course error and low right crosstrack distance.

5.3.1 Steering Cues

Evaluation of the various DIGITAL display steering cues (i.e., course error and heading to steer) was based upon trackkeeping performance prior to the turn and beyond the point at which check rudder was applied. Because steering cues were extinguished once the turn was initiated and only turn rate and recommended turn rate were presented to the subject, it is unlikely that steering cue information would have much effect upon his turning performance.

Table B-4 shows the group means for those runs in which either no steering cue was provided, course error was provided, or heading to steer was provided. There is no statistically significant difference for any measure of crosstrack distance (lines 1 and 2) nor at the time of initial rudder application. The significantly high (78 feet left) crosstrack distance at check rudder cannot be attributed to the steering cue variables since they were not displayed during the turn.

Table B-4 and Figures D-4, D-5 and D-6 of Appendix D show variability among the groups which used each of the steering cue variables. The two most important measures (lines 12 and 13) show a significantly ($p < 0.10$) higher crosstrack variability at 0.25 nm before the bend when heading to steer was used; and at 0.25 nm beyond the bend when no steering cue was used. This high variability in steadying-up beyond the bend when no steering cue is provided can be attributed to an immediate lack of set and drift information following the turn. Such information would become apparent in time, but its absence caused considerable variability among the subject group well beyond the bend. When course error or heading to steer information was displayed, set and drift information was immediately available and revealed in signficantly less group crosstrack variability.

Significantly high crosstrack variability which occured before the bend when heading to steer information was displayed (line 12), is also reflected in high crosstrack variability at the time initial rudder was applied (line 16). Further, initial rudder analysis shows that course error variance was highest when course error was displayed as was distance from the bend at the time of initial rudder application. The comparable performance between variables shown on Table B-4 suggests that the display of course error may have allowed subjects a broader individual discretion on when and how to apply their initial turning rudder. Note also in Table B-4 that although course error at initial rudder (line 4) is not significant at the p 0.10 level, it is considerably higher than the other variables; yet resultant crosstrack distance at 0.25 nm from the bend is very low.

It can be concluded that by knowing their course error subjects may have been more inclined to permit ownship to drift into the bend considerably before the time the actual initial rudder was required. This is a normal and frequently desirable

behavior in pilotage because it augments development of a swing when the swing is finally required. Probably the worse situation would be to have a right turn rate at the time a left turn is to be initiated. This could occur in instances where trackkeeping right up to the haul point is too rigidly maintained.

In general, the statistical comparison of measures shows both steering cues and the absence of steering cues to have promoted comparable and very satisfactory performance in the conduct of the miniexperiment. Subjects expressed no preference for either course error or heading to steer cues. Most agreed that as a result of their relatively brief experience with the display's capabilities they were reluctant to rely upon it for steering information and instead conducted much of the pilotage using their gyro compass as the primary source.

5.3.2 Turning Cues

Turning cues on the DIGITAL display which were varied in the miniexperiment primarily dealt with signaling to the pilot how rapidly he was approaching the bend and when to apply initial turn rudder. As such, the only measures applicable to an evaluation of turning cues are position and attitude of ownship at the time of initial rudder.

The major difference between distance to leadline and time to leadline is in the subject's knowledge of his speed over the ground and his ability or desire to convert it to a type of "countdown" routine. Distance or time to leadline could also be useful in helping the pilot determine his alongtrack position and how much his ship is being affected by following or head currents.

In both cases where turning cues were statistically compared (see Table B-5 and Figures D-7 and D-8) there is little evidence to support the recommendation of one type over the other. Table B-5 shows no statistically significant difference in performance for either distance to leadline or time to leadline where initial rudder behaviors are measured. In Table B-5 significantly ($p < 0.10$) larger variability is shown for three initial rudder measures (lines 15 through 17). This implies a larger variance among the groups of subjects when they used the distance to leadline cue.

While Table B-5 shows resultant comparable performance between both variables, when the distance variable was presented subjects applied their initial turn rudder with far less consistency. This behavior could be attributed either to a more selective application of the rudder by knowing actual distance values, or only the fact that the distance increments (i.e., tenths of a nm) tended to imply lower precision requirements than tenths of a second which was shown on the time display. Actually, mean crosstrack distance, distance from the bend, and course error were not sufficiently large to say that either was a significantly better or worse performance.

In summary, it could not be determined from the analysis of performance whether distance or time to leadline promoted a more effective turning behavior. The only remaining method of comparing the two variables was to elicit some opinion and/or preference from those individuals who had used the displays, the subjects.

5.3.3 Subject Appraisal and Observations

A majority of subjects stated that the DIGITAL display information which was not varied as part of the miniexperiment (i.e., crosstrack distance, crosstrack speed, turn rate, and recommended turn rate) was most essential to the pilotage. Either time to leadline or distance to leadline were adequate to signal approach of the bend. Subjects did not feel course error or heading to steer added much new information.

The presentation of units of measure was considered unsatisfactory. Subject recommendations were as follows:

CROSSTRACK DISTANCE - to nearest foot

CROSSTRACK SPEED - to nearest foot per minute

COURSE ERROR - to nearest degree

HEADING TO STEER - to nearest degree

TURN RATE - to nearest degree per minute

RECOMMENDED TURN RATE - to nearest degree per minute

DISTANCE TO LEADLINE - to nearest 0.10 nm or foot

TIME TO LEADLINE - to nearest second (giving hours, minutes, seconds)

Additional comments were as follows:

1) Recommended turn rate should never exceed the actual capabilities of the ship.

2) Recommended turn rate should extinguish and steering cues return when course error is within 5 degrees of the new leg. (System presently operates within 3 degrees and may not be providing sufficient advance notice to apply appropriate check rudder.)

3) Leadline should be repositioned to accommodate a higher turn rate maneuver (Display presently requires only 10 degrees rudder; 15 to 20 degrees would be more appropriate)

4) Course error and heading to steer might be better used if its reliability, accuracy, and implementation could be proven to each user.

5) Overall display concept is difficult to envision initially but can be used as long as major transgressions from track or unusual ship attitudes do not develop.

5.4 EFFECTIVENESS OF GRAPHIC DISPLAY VARIABLES

Ten GRAPHIC displays were evaluated in the miniexperiment to determine the most effective method of presenting motion, orientation, vector, and ownship image cues on a navigation display. Table B-6 shows the performance measures of subject groups using each GRAPHIC display. A statistical comparison was performed between display variables (see Tables B-7 through B-10). Most of the measures in Table B-6 fall within the range of acceptable performance and some exhibit exceptional results. This is also verified by a review of the combined track plots for

the GRAPHIC variables (Figures D-15 through D-31). For example, crosstrack distance at 0.25 nm before the bend showed that 83 percent of all subjects were able to keep the centerline of ownship within 32 feet of the channel centerline. At 0.25 nm beyond the bend, after completing a 35-degree turn in a 500 foot channel at approximately 8 knots, 83 percent of all subjects came only within one ship width of the outside channel boundary. This is commendable shiphandling performance considering the scenario difficulty and lack of visual references (e.g., buoys, landmarks).

One additional factor illustrated in Figure 17 is that while initial rudders applied for all GRAPHIC displays were well on center and tightly grouped at 0.12 nm from the bend, all check rudders were applied consistently to the right of the centerline and in a relatively large pattern. This implies some overshoot as a result of the turn maneuver and the possibility that certain display variables may have contributed to the overall performance difference more than others.

5.4.1 Motion Cues

The two motion cues evaluated on the GRAPHIC display were true motion in which ownship originated at the bottom of the display and moved across it; and relative motion in which ownship remained in the center of the display and the channel moved relative to it. Measures of performance when using the two motion cues were presented in Table B-7 and Figures D-15 and D-16. Track-up orientation was employed in both cases.

The statistical comparison at the $p < 0.10$ level of confidence shows course error (line 4) at initial rudder to be greater for the true motion variable.

In retrospect, this measure alone provides little conclusive evidence for or against the display. However, combined with the highly significant ($p < 0.10$) variance of course error (Table B-7, line 15), it suggests that the attitude of a moving object in a stationary field may be more difficult to judge than if it were fixed in a moving field. This single course error measure, however, is not sufficient evidence to warrant additional hypotheses, particularly since extensive research has been conducted comparing true and relative motion effectiveness; and conclusive differences have never been proven. Results of the studies tend to support individual preference as the predominant motivating factor in true versus relative motion display effectiveness.

In summary, the miniexperiment provides no conclusive evidence to recommend the inclusion or exclusion of either true or relative motion GRAPHIC displays from the subsequent, full-length simulation experiments. Subject preference of motion cues is discussed in Section 5.4.5.

5.4.2 Orientation Cues

Two orientation cues, track-up and head-up were compared in the miniexperiment. Statistical results of the comparison are shown in Table B-8 and Figures D-16 and D-17. Although not overwhelming, there is some statistically significant and some "trend" evidence to suggest that the track-up orientation may have produced superior pilotage performance in the miniexperiment.

All significant differences in course error at initial rudder (Table B-8, lines 4 and 15) and other measures of variability favor those runs in which track-up orientation

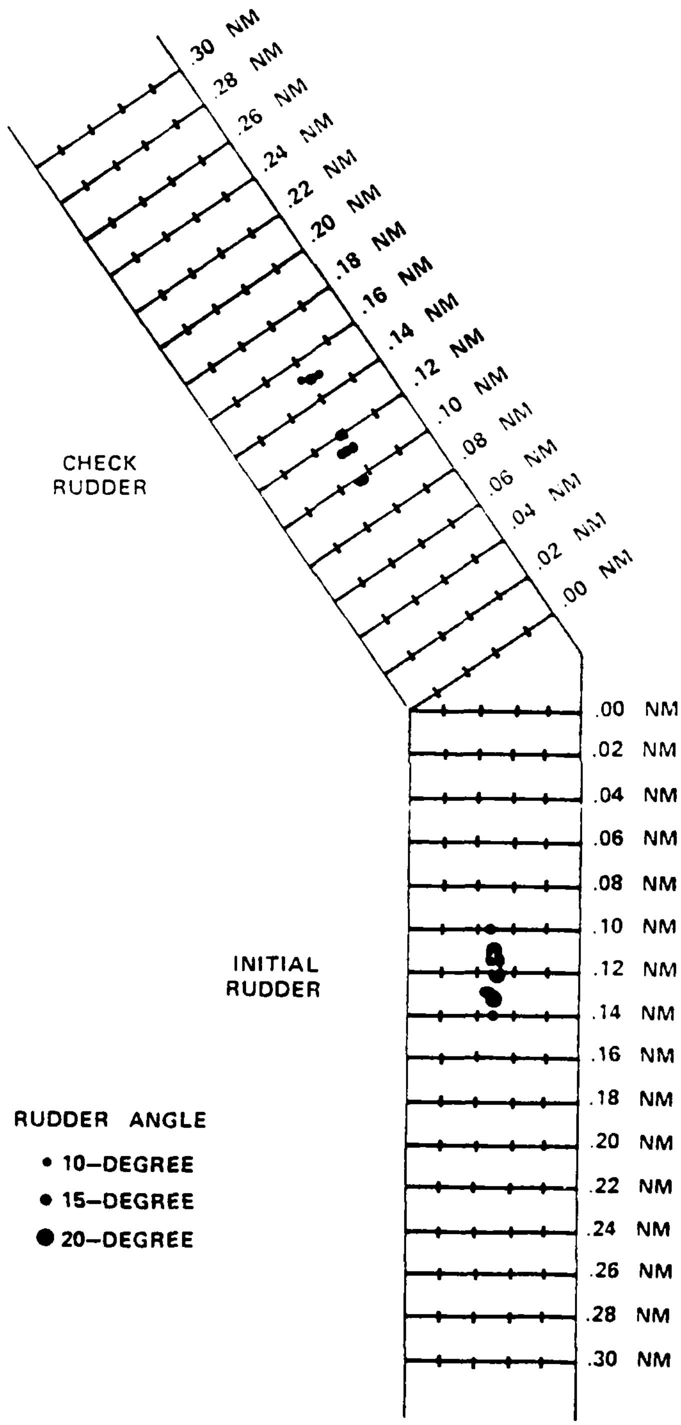


FIGURE 17. GRAPHIC DISPLAY — INITIAL RUDDER AND CHECK RUDDER

was used. The measure of crosstrack distance 0.33 nm beyond the bend (line 2) while not statistically significant shows a major trend toward less overshoot and less variability (line 13) when track-up orientation was used.

It can be concluded from this statistical comparison of orientation cues that the relatively novel approach of a track-up orientation is at least as effective as the traditional head-up display. In certain situations which remain to be more specifically identified, the track-up orientation may be superior to head up displays.

5.4.3 Vector Cues

Two types of ship vectors were evaluated in the miniexperiment, a heading vector emitting from ownship and extending to the edge of the screen, and a course vector (projected course made good) extending from ownship out for the distance ownship would travel in three minutes. Table B-9 shows course error at the time of check rudder to be the only statistically significant ($p < 0.10$) measure between the two vector cues. An analysis of all three dependent check rudder measures (lines 8 through 10) suggests only that the check rudder was applied earlier when heading vectors were used than when course vectors were used. In both instances there was some overshoot of the new leg centerline. This is reflected in right crosstrack distance both at the point of check rudder and at 0.25 nm beyond the bend (line 2). It is much less evident in Figures D-18 and D-19 which portray comparable trackkeeping through the bend.

Variability of the subject groups (Table B-9) is highest for both course error (lines 4 and 8) and location when rudders were applied (lines 17 and 21) when subjects used the course vector display. Interpretation of the standard deviation, suggests that even though the means of measures implied no difference between vectors, it was probably easier for subjects to use the more familiar heading vector than a new course vector with which they were unfamiliar. Use of the course vector was observed to be substantially different than the heading vector. It was not easy for pilots to relate to the course vector, and they appeared somewhat unsure as to how it should appear through the duration of the turn. This display feature might be more effectively evaluated if subjects were given a more extensive familiarization or practice session.

Some consideration should also be given to displaying both heading and course vectors on the GRAPHIC display. It would, of course, be necessary to have the vectors uniquely coded to ensure adequate discrimination. The presentation of both vectors would introduce drift angle information to the display, resulting in perhaps a more familiar cue than ship's course itself.

Both the findings and limitations of the brief miniexperiment do not justify a conclusion on incorporating such an important and potentially controversial item as the vector to be displayed in subsequent experiments. As a result it is recommended that both heading and course vectors be re-evaluated in the full-length scenario. At that time a more extensive subject familiarization of the course vector should be implemented. If time permits, the simulation of combined vectors to show drift angle is also recommended. A discussion of subject preference for vector design is presented in Section 5.4.5.

5.4.4 Ownship Image Cues

Two types of ownship's image for the GRAPHIC display were evaluated in the miniexperiment. Except for course error at initial and check rudder (Table B-10) there were few significant differences in performance between when a scaled image (actual shape and scaled size of ownship) and a symbolic image (+) were used. This is further verified in Figures D-20 and D-21.

As with vector cues, analyzing all three check rudder measures (lines 8 through 10) suggests that check rudder was applied earlier with the scaled image, but that both cues resulted in substantial overshoot. While not statistically significant, it is noteworthy that only 15 degrees of rudder were used for the scaled image with 67 percent of the subjects increasing this rudder through the turn. When the symbolic image was used, subjects applied 20 degrees of rudder and only 33 percent of them subsequently increased it. This behavior suggests that subjects might have been more willing to ease into the turn knowing at all times the exact position of their hull in relation to the channel boundaries.

In summary, the miniexperiment did not uncover any significant performance decrement as a result of the image cue design. Never the less it is suggested that if an accurate representation of ownship can be described on the screen, the added confidence in knowing its exact perimeters and limitations might provide the pilot with maneuvering alternatives or contingencies not otherwise available. Subject preference for ownship image cues are discussed in the following section.

5.4.5 Subject Appraisal and Observations

Subjects strongly preferred the GRAPHIC display over the other DIGITAL and PERSPECTIVE display concepts. The way information was presented on the GRAPHIC display seemed of lessor concern to them. Subjects' strongest preference was that the ship's image be scaled rather than symbolically represented since they considered the scaled image much easier to use especially in the turn.

The majority of subjects had no preference for the other GRAPHIC variables and believed they had done, or could have done equally well with either. The subjects who had an opinion preferred:

- head-up rather than track-up orientation
- relative rather than true motion
- heading rather than course vector

The results of these opinions are far from conclusive primarily because subjects were not found to respond or they may have based their preference on individual performance while using the display. It is strongly recommended that a structured survey be developed and administered in the subsequent experiments, one which elicits not only subject opinions, but a self-appraisal of their own performance and a relative critique of display variables.

5.5 EFFECTIVENESS OF PERSPECTIVE DISPLAY VARIABLES

In the original design of the PERSPECTIVE display, it was recognized that major contributing factors to the display's effectiveness would be height of eye, distance

of eye from the bow, and field of view. A basic premise in the design rationale was that the display was not intended to replicate the actual scene or viewed from the ship's windows; but instead, ownship and the waterway would appear as a generic picture presenting effective navigation information regardless of the hull shape or bridge location on which the display was installed.

For this reason, height of eye and bow configuration were selected to provide maximum discrimination of drift angle and view abeam without artificially distorting the geographic perspective. It was decided to select through experimentation the one remaining variable which appeared to be most critical to the display's effectiveness; this was field of view.

5.5.1 Field of View

Figure 18 illustrates the location and magnitude (although not statistically significant) of both initial and check rudders which were applied by subject groups using the PERSPECTIVE display. Table B-11 (line 2) shows that both the 60-degree and 90-degree fields of view produced approximately one ship width overshoot of the channel centerline 0.25 nm beyond the bend. Analysis of the mean measures of check rudder (lines 8 and 9, also not statistically significant) suggest that check rudder was applied late when using both the 60-degree and 90-degree displays. These measures, combined with ownship's location (line 10) at the time check rudder was applied, suggest that a very high turn rate probably occurred in the maneuver.

There were no significant differences in the 83 percent incident of increased initial rudder, although this percentage is high compared to the other display concepts. Table B-11 (line 12) shows a significantly higher, but by no means deleterious, crosstrack variance among the groups using the 90-degree field of view variable. It also shows a significantly ($p < 0.10$) higher level of course error variability at both initial and check rudder when the 60-degree field of view was used. Considering that resultant crosstrack performance was comparable, it must be assumed that the 90-degree display produced a higher consistency in trackkeeping up to and at the point of initial rudder application.

In summary, there was little statistical evidence to support the conclusion that one of the fields of view was more effective than the other. Either 60-degree or 90-degree appears appropriate although the 60-degree field of view tended to promote increased subject consistency in returning to the centerline beyond the bend. This is well illustrated in a review of Figures D-32 and D-33.

5.5.2 Subject Appraisal and Observations

Three of the subjects had no preference for the field of view. Two preferred the 60-degree display, and one the 90-degree display. Most stated they saw very little operational difference, but were surprised at how fast the point of the bend disappeared from "view" once they entered the turn using the 60-degree display. In general, subjects were more concerned with the lack of forward velocity cues (see Section 5.2.3), than they were the loss of abeam distance cues.

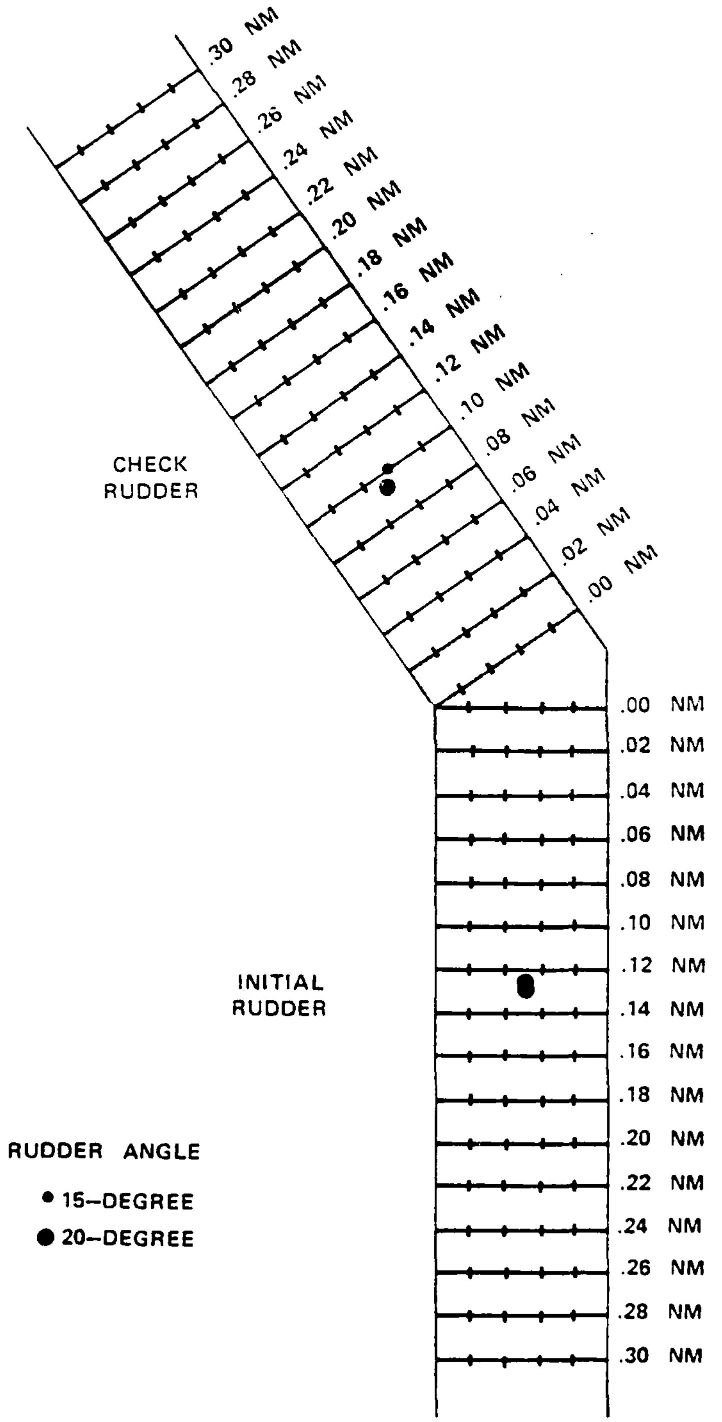


FIGURE 18. PERSPECTIVE DISPLAY — INITIAL RUDDER AND CHECK RUDDER

Section 6

RECOMMENDATIONS

Miniexperiment results suggest that all display concepts (DIGITAL, GRAPHIC, and PERSPECTIVE) be represented in the full-scale perfect position experiment. It is also recommended that several of the performance measures be expanded to produce a more refined analysis, one with increased validity and statistical power, and the ability to compare subtle shiphandling behaviors. These areas are discussed below.

6.1 PROPOSED DISPLAYS

The following displays have been selected for further evaluation in the Radio Aids to Navigation Display project:

a. Two DIGITAL displays. The first display will provide only crosstrack distance and distance to leadline. The second display will provide:

- Trackkeeping information
  - Crosstrack distance
  - Crosstrack speed
- Turnmaking information
  - Distance to turn apex
  - Turn rate
  - Recommended turn rate

Recommended changes to improve the DIGITAL display are:

- Arrows indicating direction should be larger or replaced by "R" and "L"
- Information displayed should be rounded to the nearest unit (i.e., feet, degree, second)
- The location of the leadline or turn initiation point should be determined by the pilot
- Leadline should be moved to accommodate a 20-degree rudder
- Recommended turn rate should be extinguished within 5 degrees of the new leg and would display no higher than the maximum turn rate achievable by the ship

b. Four GRAPHIC displays. These displays will be track-up, true motion with a scaled ship's image. Experimental variables will be:

- Heading vector
- Course vector
- Simplified prediction vector
- Track prediction vector

Recommended changes to improve the GRAPHIC display are:

- Range scale should be 0.75 nm

- Prediction time should be 1-1/2 minutes

c. One PERSPECTIVE display. This display will provide a 90-degree field of view.

Figure 19 summarizes the proposed displays.

6.2 COST ANALYSIS OF DISPLAY FORMATS

One of the principal goals of the radio aids display research is to relate piloting performance to display complexity and state-of-the-art costs. The cost, hardware requirements, and information requirements for the selected displays are listed in Table 8. The digital displays are the least expensive (under $1000), but also provide the least information. The perspective display, graphic display with course vector, graphic display with heading vector, and graphic display with recommended turn rate and turn rate vectors are in the medium price range at $3000 each. The graphic display with a predictor vector is the most costly at $6000.

Figure 20 shows the system configurations for the selected display formats and also shows the possibility of providing rate aiding to the filter and use of only position data for display purposes or position and velocity data.

6.3 PROPOSED PERFORMANCE MEASURES

Data should be recorded and analyzed as demonstrated in the miniexperiment. This will enable a comparison of performance both between miniexperiments and the full-length scenario experiments, and between radio aids display simulations and visual simulations. The following measures for subsequent radio aids to navigation display experiments are:

a. Trackkeeping

- Crosstrack distance to right or left of channel centerline at 475 intervals
- Mean group tracks
- Variance of group about their mean
- Alongtrack distance for initial and check rudders

b. Shiphandling commands

- Frequency of rudder, course, and engine orders
- Duration of rudder, course, and engine orders
- Incidence of rudder versus course orders
- Extent of modification to initial rudders and where rudder is applied in relation to the bend (ship's crosstrack position in channel and course error)

c. Subject analysis

- Experimenter's observations and subject's comments
- Structured questionnaire to identify subject's perspection of performance and to compare each run with previous runs

DIGITAL DISPLAY VARIABLE

	TRACKKEEPING INFORMATION	TURNMAKING INFORMATION
LEVEL 1	CROSSTRACK DISTANCE	DISTANCE TO LEADLINE
LEVEL 2	CROSSTRACK DISTANCE CROSSTRACK SPEED	DISTANCE TO LEADLINE TURN RATE RECOMMENDED TURN RATE

GRAPHIC DISPLAY VARIABLE

	DISPLAY ORIENTATION	SHIP VECTOR	SHIP IMAGE
LEVEL 1	TRACK-UP TRUE *MOTION*	HEADING	SCALED
LEVEL 2		COURSE	
LEVEL 3		PREDICTOR	
LEVEL 4		SIMPLIFIED PREDICTOR	

PERSPECTIVE DISPLAY VARIABLE

	FIELD OF VIEW
LEVEL 1	90°

FIGURE 19. PROPOSED DISPLAYS FOR FULL-LENGTH SCENARIOS

TABLE 8. RADIO AID DISPLAYS COST, HARDWARE, AND INFORMATION REQUIREMENTS

DISPLAY TO BE EVAULATED	ESTIMATED COST	HARDWARE REQUIREMENTS	TURN RATE AIDING	PORTABILITY
DIGITAL (CTD, DTL)	$200	MICROCIRCUIT POSITION RESOLVER	NO	YES
DIGITAL (CTD, CTS, DTL, RTR, TR)	$750	8080 MICROPROCESSOR RAM MEMORY	NO	YES
GRAPHIC (TRUE MOTION, SCALED IMAGE, COURSE VECTOR)	$3000	GRYO INTERFACE 8080 MICROPROCESSOR RAM MEMORY CRT DISPLAY CONTROL CRT DISPLAY	YES	NO
GRAPHIC (TRUE MOTION, SCALED IMAGE, HEADING VECTOR)	$3000	GYRO INTERFACE 8080 MICROPROCESSOR RAM MEMORY CRT DISPLAY CONTROL CRT DISPLAY	YES	NO
GRAPHIC (TRUE MOTION SCALED IMAGE, SIMPLIFIED PREDICTION VECTOR, RATE VECTORS)	$3000	GYRO INTERFACE 8080 MICROPROCESSOR RAM MEMORY CRT DISPLAY CONTROL CRT DISPLAY	YES	NO
GRAPHIC (TRUE MOTION SCALED IMAGE, PREDICTOR POSITION)	$6000	GYRO INTERFACE DUAL AXIS SPEED LOG INTERFACE HIGH SPEED MICROPROCESSOR OR MINICOMPUTER RAM MEMORY CRT DISPLAY CONTROL CRT DISPLAY	YES	NO
PERSPECTIVE (90 DEGREE FIELD OF VIEW)	$3000	GYRO INTERFACE 8080 MICROPROCESSOR RAM MEMORY CRT DISPLAY CONTROL CRT DISPLAY	YES	NO

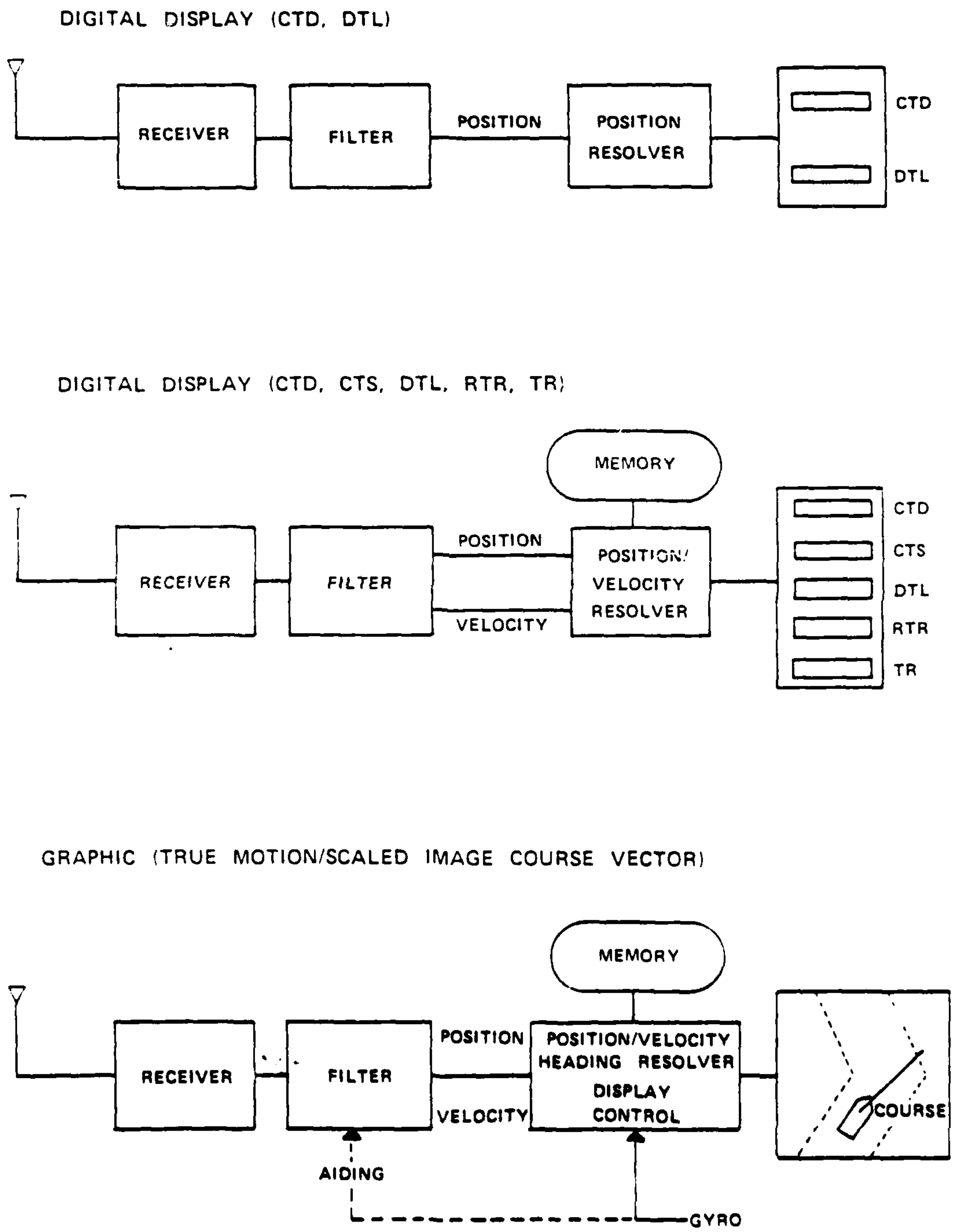
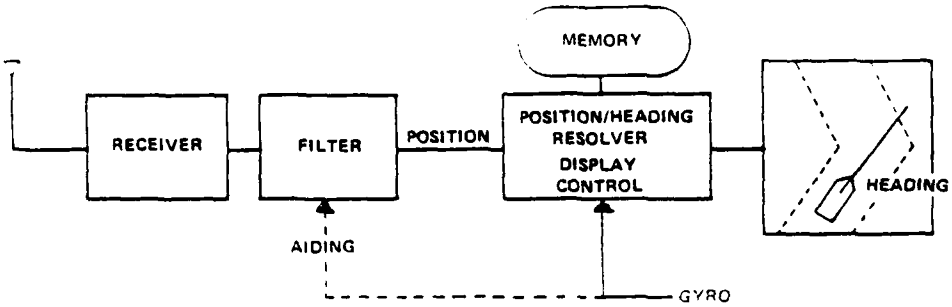
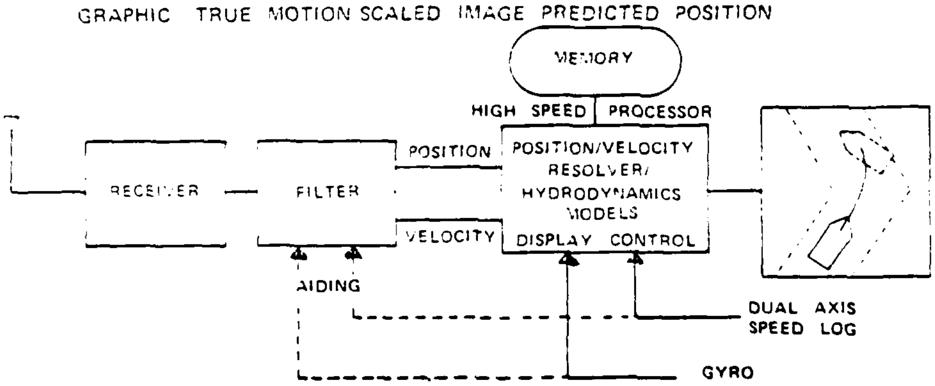


FIGURE 20. SYSTEM CONFIGURATIONS

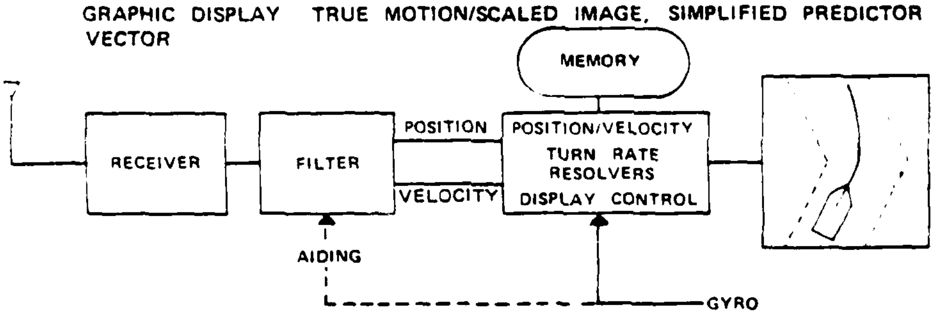
GRAPHIC TRUE MOTION/SCALED IMAGE HEADING VECTOR



GRAPHIC TRUE MOTION SCALED IMAGE PREDICTED POSITION



GRAPHIC DISPLAY TRUE MOTION/SCALED IMAGE, SIMPLIFIED PREDICTOR VECTOR



GRAPHIC PERSPECTIVE

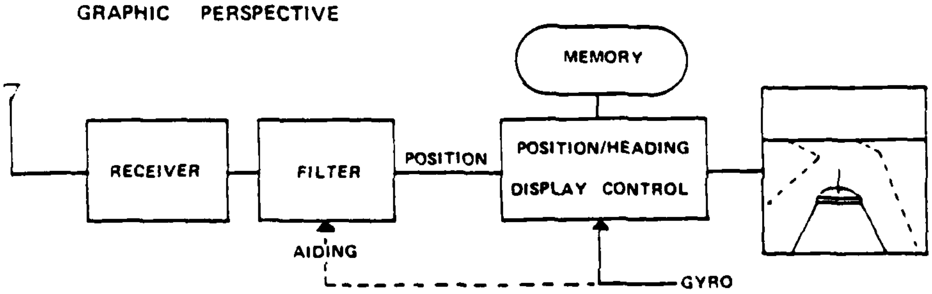


FIGURE 20. SYSTEM CONFIGURATIONS (CONTINUED)

Appendix A

INSTRUCTIONS TO SUBJECTS

Introduction. We have asked you to participate in this experiment to evaluate the effectiveness of several types of navigation displays for piloting a ship. You will use these displays separately to determine their usefulness in navigating the ship through a 500-foot channel. The different displays will be described in detail as you will use them.

Scenario. During this experiment, we will be measuring how well you keep on the channel centerline. Your goal, therefore, is to keep in the center of the channel as much as possible throughout the transit. The channel is 500-feet wide and 36-feet deep. Own ship is a 30,000 dwt tanker with the bridge midships. It has a 595-foot length overall, an 84-foot beam, and a 34-foot draft.

Your initial starting position will be approximately 1 nm from a 35-degree left bend in the channel. Your heading is 341 degrees true, and the ship's speed will be 7 knots over ground at the beginning of the run. It will be controlled by the EOT which will be set initially at half speed ahead, 40 rpm. RPM changes are permitted, however, we would like you to maintain an overall 7-knot transit speed. Use of speed variations are limited to full ahead, half ahead, slow ahead, dead slow ahead, and stop. No astern bells are available.

There will be a following current of 3/4 of a knot at the beginning of the run, and there will be a wind from south/southeast at 30 knots and gusting.

A.1 INSTRUCTIONS FOR DIGITAL DISPLAY 1-1*

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- TURN RATE is shown in degrees per minute to the right or left.
- DISTANCE TO LEAD LINE is shown in nm. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK SPEED will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own

* See Figures 5 and 6 of the text.

ship's turn rate. This will bring you on centerline of the new leg. Once your course is within 3 degrees of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half speed ahead, approximately 1 nm from the turn. Are there any questions?

A.2 INSTRUCTIONS FOR DIGITAL DISPLAY 1-2

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- TURN RATE is shown in degrees per minute to right or left.
- TIME TO LEAD LINE is shown in minutes. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK SPEED will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own ship's turn rate. This will bring you on the centerline of the new leg. Once your course is within 3 degrees of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half speed ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.3 INSTRUCTIONS FOR DIGITAL DISPLAY 2-1

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- COURSE ERROR is the angular difference between the channel centerline and own ship's course. If the course error is zero you will be tracking parallel to the centerline. If the error is to the right or left, you are moving in that direction away from the centerline.
- TURN RATE is shown in degrees per minute to right or left.

- DISTANCE TO LEAD LINE is shown in nm. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK SPEED will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own ship's turn rate. This will bring you on centerline of the new leg. Once your course is within 3 degrees of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half speed ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.4 INSTRUCTIONS FOR DIGITAL DISPLAY 2-2

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- COURSE ERROR is the angular difference between the channel centerline and own ship's course. If the course error is zero you will be tracking parallel to the centerline. If the error is to the right or left, you are drifting in that direction away from the centerline.
- TURN RATE is shown in degrees per minute to the right or left.
- TIME TO LEAD LINE is shown in minutes. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK speed will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own ship's turn rate. This will bring you on centerline of the new leg. Once your course is within 3 degrees of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half speed ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.5 INSTRUCTIONS FOR DIGITAL DISPLAY 3-1

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- HEADING TO STEER is the recommended heading required for own ship to track parallel to the channel centerline.
- TURN RATE is shown in degrees per minute to right or left.
- DISTANCE TO LEAD LINE is shown in nm. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK SPEED will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own ship's turn rate. This will bring you on centerline of the new leg. Once your course is within 3 degrees of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.6 INSTRUCTIONS FOR DIGITAL DISPLAY 3-2

The display that you will use now is a digital display of own ship's position with recommendations for making the turn. The information that you will be provided in the first leg is described below.

- CROSSTRACK DISTANCE is shown in feet to the right or left of the channel centerline, and its direction is indicated by arrows.
- CROSSTRACK SPEED is shown in feet per minute in the direction that own ship is moving.
- HEADING TO STEER is the recommended heading required for own ship to track parallel to the channel centerline.
- TURN RATE is shown in degrees per minute to right or left.
- TIME TO LEAD LINE is shown in minutes. The lead line is the point at which the turn should be started. A 10-degree rudder will be required to make the turn.

Once you have reached the lead line, the information shown for CROSSTRACK DISTANCE and CROSSTRACK SPEED will be to the next leg. You will be shown a RECOMMENDED TURN RATE which you should try to continuously match with own ship's turn rate. This will bring you on centerline of the new leg. Once your course is within 3 degree of the new leg, RECOMMENDED TURN RATE will disappear. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.7 INSTRUCTIONS FOR GRAPHIC DISPLAY VARIABLE 1-1-1*

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be true motion oriented track-up. With the true motion display, own ship comes on at the bottom of the screen and resets after it has traveled 3/4 of the distance across the screen. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up and own ship will reset to the bottom of the screen.

The display is provided with a heading vector which corresponds to gyro heading and is drawn to the edge of the screen. Own ship's image is the actual shape and size of own ship scaled to the display. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.8 INSTRUCTIONS FOR GRAPHIC DISPLAY 1-1-2

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be true motion oriented track-up. With the true motion display, own ship comes on at the bottom of the screen and moves across the screen for 3/4 of the distance before it is reset. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up, and own ship will reset to the bottom of the screen.

The display is provided with a heading vector which corresponds to gyro heading and is drawn to the edge of the screen. Own ship's image is symbolically, represented by a cross (+). You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.9 INSTRUCTIONS FOR GRAPHIC DISPLAY 1-2-1

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be true motion oriented track-up. With the true motion display, own ship comes on at the bottom of the screen and moves across the screen for 3/4 of the distance before it is reset. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up, and own ship will reset to the bottom of the screen.

The display is provided with a course vector which represents the course-made-good of ownship and is drawn for the distance own ship will travel in 3 minutes. Own ship's image is the actual shape and size of own ship scaled to the display. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

* See Figure 7 of the text.

A.10 INSTRUCTIONS FOR GRAPHIC DISPLAY 2-1-1

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be relative motion oriented track-up. With relative motion the ship's image always remains in the center of the screen. In the track-up mode, the picture comes on with the channel centerline oriented up, own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up.

The display is provided with a heading vector which corresponds to gyro heading and is drawn to the edge of the screen. Own ship's image is the actual shape and size of own ship scaled to the display. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.11 INSTRUCTIONS FOR GRAPHIC DISPLAY 1-2-2

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be true motion oriented track-up. With the true motion display, own ship comes on at the bottom of the screen and moves across the screen for 3/4 of the distance before it is reset. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up, and own ship will reset to the bottom of the screen.

The display is provided with a course vector which represents the course-made-good of own ship and is drawn for the distance own ship will travel in 3 minutes. Own ship's course image is symbolically represented by a cross (+). You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.12 INSTRUCTIONS FOR GRAPHIC DISPLAY 2-1-2

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be relative motion oriented track-up. With relative motion, the ship's image is always in the center of the screen. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up.

The display is provided with a heading vector which corresponds to gyro heading and is drawn to the edge of the screen. Own ship's image is symbolically represented by a cross (+). You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.13 INSTRUCTIONS FOR GRAPHIC DISPLAY 2-2-2

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be relative motion oriented track-up. With relative motion, the ship's image always remains in the center of the screen. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up.

The display is provided with a course vector which represents the course-made-good of own ship and is drawn for the distance own ship will travel in 3 minutes. Own ship's image is symbolically represented by a cross (+). You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.14 INSTRUCTIONS FOR GRAPHIC DISPLAY 2-2-1

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be relative motion oriented track-up. With relative motion, the ship's image always remains in the center of the screen. In the track-up mode, the picture comes on with the channel centerline oriented up, and own ship moves through it. Once you have completed the turn, the display will automatically change to the new track-up.

The display is provided with a course vector which represents the course-made-good of own ship and is drawn for the distance own ship will travel in 3 minutes. Own ship's image is the actual shape and size of own ship scaled to the display. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.15 INSTRUCTIONS FOR GRAPHIC DISPLAY 3-2-1

The display that you will use now is a graphic display showing own ship's position in the channel. The display will be relative motion oriented head-up. With relative motion, the ship's image always remains in the center of the screen. The head-up mode operates similar to the head-up feature on commercially available radars.

The display is provided with a course vector which represents the course-made-good of own ship and is drawn for the distance own ship will travel in 3 minutes. Own ship's image is the actual shape and size of own ship scaled to the display. You will be on a heading of 341 degrees in the first leg, at 7 knots, half ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

A.16 INSTRUCTIONS FOR PERSPECTIVE DISPLAYS 1 AND 2*

The display that you will use now is a perspective display which represents what you would see out the window if channel boundaries were visible. The channel boundaries

* See Figure 8 of the text.

will be shown as dashed lines, however, these dashes are symbolic and do not represent distance. As a result, the dashed lines will not move along own ship as you proceed down the channel. You will be on a heading of 341 degrees in the first leg, at 7 knots, half speed ahead, approximately 1 nm from the turn. Just take the ship in normally. Are there any questions?

Appendix B

PRELIMINARY RESULTS OF TRACKKEEPING ANALYSIS

This appendix contains tables that compare the group mean and standard deviation of:

- Order of runs (first, middle, final)
- Display concepts (digital, graphic, perspective)
- Digital variables (steering and turning cues)
- Graphic variables (motion, orientation, vector, and ownship image cues)
- Perspective variables (60-degree and 90-degree field of view)

The tables summarize (1) crosstrack distance (from the centerline) before and after the bend at 0.25 nm, (2) initial rudder actuations, (3) check rudder actuations, and (4) incidence of increasing rudder at the bend.

TABLE B-1. COMPARISON OF ORDER OF RUNS

		MEASURE	FIRST RUNS	MIDDLE RUNS	FINAL RUNS
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	4—L	6—L	2—L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	107—R ★	21—R	28—R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	20	18	15
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	2.29—L	1.03—L	0.93—L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	12—R	17—L	3—L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	124	134	156
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.38—R	0.61—R	10.70—R ★
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	77—R	43—R	32—L ★
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	150	129	075 ★
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	50	50	50
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	11	23	13
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	110 ★	41	66
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	5	5
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	3.22 ★	0.85	1.04
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	20	34	19
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	087 ★	[illegible]	041
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	6.45	3.92	13.18 ★
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	97	70	71
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	066	051	019 ★

★ SIGNIFICANT AT $p \leq .10$ LEVEL OF CONFIDENCE

TABLE B-2. COMPARISON OF DISPLAY CONCEPTS

		MEASURE	DIGITAL	GRAPHIC	PERSPECTIVE
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	2–L	4–L	2–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	45–L ★	49–R	82–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10 ★	20	20
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.05–L	1.58–L	1.24–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	5–L	14–L	11–R
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	224 ★	113	115
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15	20
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	2.41–R	2.12–R	7.50–R ★
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	50–L ★	41–R	22–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.162	.122	.089 ★
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	29	47	83 ★
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	16 ★	28	20
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	64	58	72
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	5	10	10
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.95	1.78	1.17
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	29	37	25
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	034	.039	.036
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.22 ★	4.37 ★	8.83 ★
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	100	66 ★	104
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	069	054	038

★ SIGNIFICANT AT $p \leq$ 10 LEVEL OF CONFIDENCE

TABLE B-3. COMPARISON OF DIGITAL VARIABLES

		Measure	Dist to Lead Only	Time to Lead Only	Course Error: Dist to Lead	Course Error: Time to Lead	Heading to Steer: Dist to Lead	Heading to Steer: Time to Lead
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	7-L	2-R	2-L	6-L	4-R	4-L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	51-L	38-L	21-L	13-L	16-L	31-L
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10	10	10	10	10
	4	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.90-L	0.71-L	3.38-L	0.94-L	0.25-L	0.15-L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	7-L	1-L	25-L	11-L	22-R	5-L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	244	225	208	208	231	230
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	10	15	10	15	15	10
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	5.63-R	0.99-L	3.36-R	2.54-R	0.26-R	3.65-R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	144-L	12-L	73-L	31-L	22-R	62-L
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	120	190	152	162	187	160
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	17	67	17	50	20	0
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	9	10	11	11	35	18
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	64	171	28	37	46	41
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	0	5	5	0	0	5
	15	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.86	0.51	7.47	1.00	1.17	0.92
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	11	10	51	8	78	17
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	036	008	103	029	010	016
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	0	10	5	5	10	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	5.03	3.87	2.81	2.79	2.27	2.96
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	140	156	84	32	100	79
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	092	082	102	056	052	032

Note: No statistical analysis was conducted at this level of interaction. For statistical comparison see Tables B-4 and B-5.

TABLE B-4. COMPARISON OF STEERING CUES

		MEASURE	-NONE-	COURSE ERROR	HEADING TO STEER
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	3–L	4–L	0
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	44–L	17–L	24–L
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10	10
	4	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.81–L	2.15–L	0.20–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	4–L	18–L	9–R
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	235	208	231
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	2.32–R	2.95–R	1.96–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	78–L ★	52–L	20–L
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.155	157	.174
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	42	34	10
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	10	11	27 ★
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	118 ★	33	43
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	5	5	5
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	0.58 ★	4.24 ★	1.05 ★
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	11 ★	30 ★	48 ★
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	022	066 ★	013
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	4.36 ★	2.70	2.82
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	152 ★	58 ★	88 ★
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	087	079	042 ★

★ SIGNIFICANT AT $p \leq .10$ LEVEL OF CONFIDENCE

TABLE B-5. COMPARISON OF TURNING CUES

		MEASURE	DISTANCE TO LEADLINE	TIME TO LEADLINE
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	2–L	3–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	29–L	27–L
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.50–L	0.60–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	3–L	6–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	228	221
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	10	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.09–R	1.73–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	65–L ★	35–L
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	228	171
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	18	39
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	18 ★	13
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	46 ★	83
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	0	5
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	3.10 ★	0.81
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	47 ★	12
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	050 ★	018
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.30	3.14
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	108	89
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	092 ★	75

★ SIGNIFICANT AT $\alpha \leq .10$ LEVEL OF CONFIDENCE

TABLE B-6. COMPARISON OF GRAPHIC VARIABLES

		MEASURE	TRACK-UP TRUE MOTION				TRACK-UP RELATIVE MOTION				HEAD-UP R M	
			HEADING		COURSE		HEADING		COURSE		HEADING	COURSE
			SCALED	SYMBOLIC	SCALED	SYMBOLIC	SCALED	SYMBOLIC	SCALED	SYMBOLIC	SCALED	SYMBOLIC
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	16–L	2–R	6–L	12–L	2–R	1–R	2–R	12–L	16–R	2–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	25–R	39–R	41–R	32–R	64–R	49–R	30–R	57–R	82–R	69–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	15	20	15	20	20	20	15	20	20	20
	4	COURSE ERROR AT INITITAL RUDDER (DEGREES)	1.19–L	1.24–L	0.84–L	4.24–L	0.37–L	1.06–L	0.76–L	1.32–L	2.53–L	2.27–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	22–L	14–L	21–L	24–L	3–L	11–L	6–L	26–L	2–L	10–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	.130	.119	130	.103	.128	134	.142	.116	.114	.110
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15	15	10	15	15	15	15	15	10
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.53–R	1.55–R	2.13–R	0.48–L	2.05–R	2.83–R	3.29–R	1.18–L	3.85–R	0.26–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	7–R	46–R	40–R	61–R	50–R	31–R	2–R	76–R	55–R	46–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.096	.120	.115	.150	.113	.114	.097	.150	.112	.153
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	50	33	67	0	67	50	83	50	33	33
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	31	26	30	26	30	34	25	36	13	24
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	38	54	52	53	71	33	54	65	55	105
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	5	5	10	10	5	5	10	10	10	5
	15	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.70	1.05	0.92	5.38	0.49	0.65	0.60	0.68	4.18	3.16
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	42	34	42	33	36	43	32	46	28	32
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	.030	.023	.027	.082	.035	.025	042	.037	.086	.081
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5	5	5	5	5	5	5	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.94	4.21	3.01	3.96	4.49	5.06	5.43	4.38	2.27	6.99
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	50	43	64	50	88	53	76	67	69	100
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	024	046	038	076	.055	.055	048	064	032	114

Note: No statistical analysis was conducted at this level of interaction. For statistical comparison see Tables B-7 through B-10.

TABLE B-7. COMPARISON OF MOTION CUES

		MEASURE	TRUE MOTION (TK-UP)	RELATIVE MOTION (TK-UP)
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	8–L	2–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	34–R	50–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	20	20
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.87–L ★	0.79–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	20–L	12–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	121	.130
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	1.68–R	1.75–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	39–R	40–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	120	.119
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	38	63
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	28	31
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	49	56
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	2.01 ★	0.61
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	38	39
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	041	.036
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.78 ★	4.84
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	52 ★	71
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	046	053

★ SIGNIFICANT AT $\alpha \leq .10$ LEVEL OF CONFIDENCE

TABLE B-8. COMPARISON OF ORIENTATION CUES

		MEASURE	TRACK-UP (R.M.-SCALED)	HEAD-UP (R.M.-SCALED)
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	2-R	2-R
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	47-R	75-R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	20	20
	4	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.57-L ★	2.40-L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	5-L	6-L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	135	.112
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	2.67-R	2.06-R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	28-R	51-R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.106	133
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	75 ★	33
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	28 ★	19
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	63 ★	80
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10
	15	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.56 ★	3.67
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	34	30
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	.038 ★	.066
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	4.96	4.63
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	82	85
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	052 ★	088

★ SIGNIFICANT AT $p \leq .10$ LEVEL OF CONFIDENCE

TABLE B-9. COMPARISON OF VECTOR CUES

		MEASURE	HEADING	COURSE
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	1–L	6–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	52–R	46–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	20	20
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1 28–L	1 89–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	10–L	17–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	125	120
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	2 76–R ★	0 80–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	28–R	45–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	111	133
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	47	47
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	27	28
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	50 ★	68
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	5	10
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1 41 ★	2.15
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	37	37
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	034 ★	050
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	3.77 ★	4.75
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	61	71
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	042 ★	066

★ SIGNIFICANT AT $\alpha <$ .10 LEVEL OF CONFIDENCE

TABLE B-10. COMPARISON OF OWNSHIP IMAGE CUES

		MEASURE	SCALED	SYMBOLIC
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	5–L	5–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	40–R	44–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	15	20
	4	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.70–L ★	1.97–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	13–L	19–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	.132	.118
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	15	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	2.75–R ★	0.68–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	25–R	54–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.105 ★	.134
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	67 ★	33
STANDARD DEVIATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	29	31
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	54	51
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	10	10
	15	COURSE ERROR AT INITITAL RUDDER (DEGREES)	0.68 ★	1.94
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	38	39
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	.034	.042
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	4.22	4.40
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	70 ★	53
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	.041 ★	.058

★ SIGNIFICANT AT $p < .10$ LEVEL OF CONFIDENCE

TABLE B-11. COMPARISON OF PERSPECTIVE VARIABLES

		MEASURE	60° FIELD OF VIEW	30° FIELD OF VIEW
GROUP MEAN	1	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	0	4–L
	2	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	74–R	90–R
	3	MAGNITUDE OF INITIAL RUDDER (DEGREES)	20	20
	4	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.49–L	0.98–L
	5	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	10–L	11–L
	6	DISTANCE TO BEND AT INITIAL RUDDER (NM)	118	112
	7	MAGNITUDE OF CHECK RUDDER (DEGREES)	20	15
	8	COURSE ERROR AT CHECK RUDDER (DEGREES)	10.63–R	4.37–R
	9	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	0	43–R
	10	DISTANCE FROM BEND AT CHECK RUDDER (NM)	078	1.00
	11	INCIDENCE OF INCREASING RUDDER IN BEND (%)	83	83
STANDARD DEIVATION	12	CROSSTRACK DISTANCE 1/4 NM BEFORE BEND (FEET)	12 ★	27
	13	CROSSTRACK DISTANCE 1/4 NM BEYOND BEND (FEET)	86	57
	14	MAGNITUDE OF INITIAL RUDDER (DEGREES)	5	10
	15	COURSE ERROR AT INITIAL RUDDER (DEGREES)	1.78 ★	0.58
	16	CROSSTRACK DISTANCE AT INITIAL RUDDER (FEET)	15 ★	34
	17	DISTANCE TO BEND AT INITIAL RUDDER (NM)	039	030
	18	MAGNITUDE OF CHECK RUDDER (DEGREES)	5	5
	19	COURSE ERROR AT CHECK RUDDER (DEGREES)	13.54 ★	3.72
	20	CROSSTRACK DISTANCE AT CHECK RUDDER (FEET)	96	112
	21	DISTANCE FROM BEND AT CHECK RUDDER (NM)	032	344

★ SIGNIFICANT AT p ≤ .10 LEVEL OF CONFIDENCE

Appendix C
AN/RA SIMULATION CHECKLIST

LOCATION	TASK	TEST DIRECTOR	HELMSMAN
Prearrival	Inform receptionist of whereabouts and subject's name	X	
	Helmsman present	X	X
	Simulator operator present	X	
	AN/RA program checkout (first scheduled run — RUN 0, SUBJECT 0)	X	X
	Bridge arrangement and checkout with program — set ambient light		X
	Select proper run sheet	X	
	Put instructions in order according to run sheet	X	
Reception	Greet subject	X	
	Introduce to "whomever"	X	
	Offer coffee	X	
	Fill out paper work	X	
Bridge	Introduce to helmsman	X	X
	Point out "Navigation display" and brightness control	X	
	Visual scene	X	
	OH repeater	X	
	Console repeater	X	
	RAI	X	
	EOT	X	
	RPM	X	
	Clock	X	
Chart Table	Check for chart, dividers, rules, pencils	X	
	Read scenario instructions	X	
	Call simulator operator "bring up run #___"	X	
Nav Display	Read display instructions and check to see if proper display variables	X	
Preinitialize	Set: Clock 10:00		X
	OH repeater 341°		X
	Console repeater 341°		X
	Rudder midships 0°		X

AN/RA SIMULATION CHECKLIST (CONT'D)

LOCATION	TASK	TEST DIRECTOR	HELMSMAN
Initialize	Call simulator operator to "start run #___"	X	
	Write in run #___ on run sheet	X	
	Check display to see if operating properly	X	
	Watch clock for 10:12	X	
	Cross off run data on run sheet	X	
	Call simulator operator to stop run, "bring up run #___ and wait for my call before starting"	X	
End of Day	Set up bridge for Visual Experiment		X
	Turn off bridge (unless requested otherwise)		X
	Pick up Decwriter printout and staple to run sheet	X	
	Thank and dismiss helmsman	X	X
	Thank and dismiss subject	X	

Appendix D

COMBINED TRACK PLOTS

The data provided in this appendix are combined track plots of all runs for selected experimental conditions. The ships' mean CG (center of gravity) track is plotted along with +/- twice the crosstrack standard deviation of tracks. The waterway extends from 0.3 nautical miles beyond it. These plots may be compared on a one to one basis with the "Trackkeeping Plots" and "Initial Rudder and Check Rudder Plots" of Section 4. They are used primarily for the interpretation of pilotage performance which is statistically analyzed in Section 4.

Appendix D is divided into three sections:

Section D-1 contains plots of the main differences between digital, graphic and perspective displays.

Section D-2 contains plots which allow evaluation of all digital display variables.

Section D-3 contains plots which allow evaluation of all graphic variables.

Section D-4 contains plots which allow evaluation of all perspective display variables.

NOTE: Where specific variables are identified for each condition, all other variables are combined. For example, D-1 is for a true motion, track-up display with either type of vector or ship image.

Section D.1

DISPLAY CONCEPT VARIABLES

Data in this section allow comparison of trackkeeping performance between:

- All Digital Displays
- All Graphic Displays
- All Perspective Displays

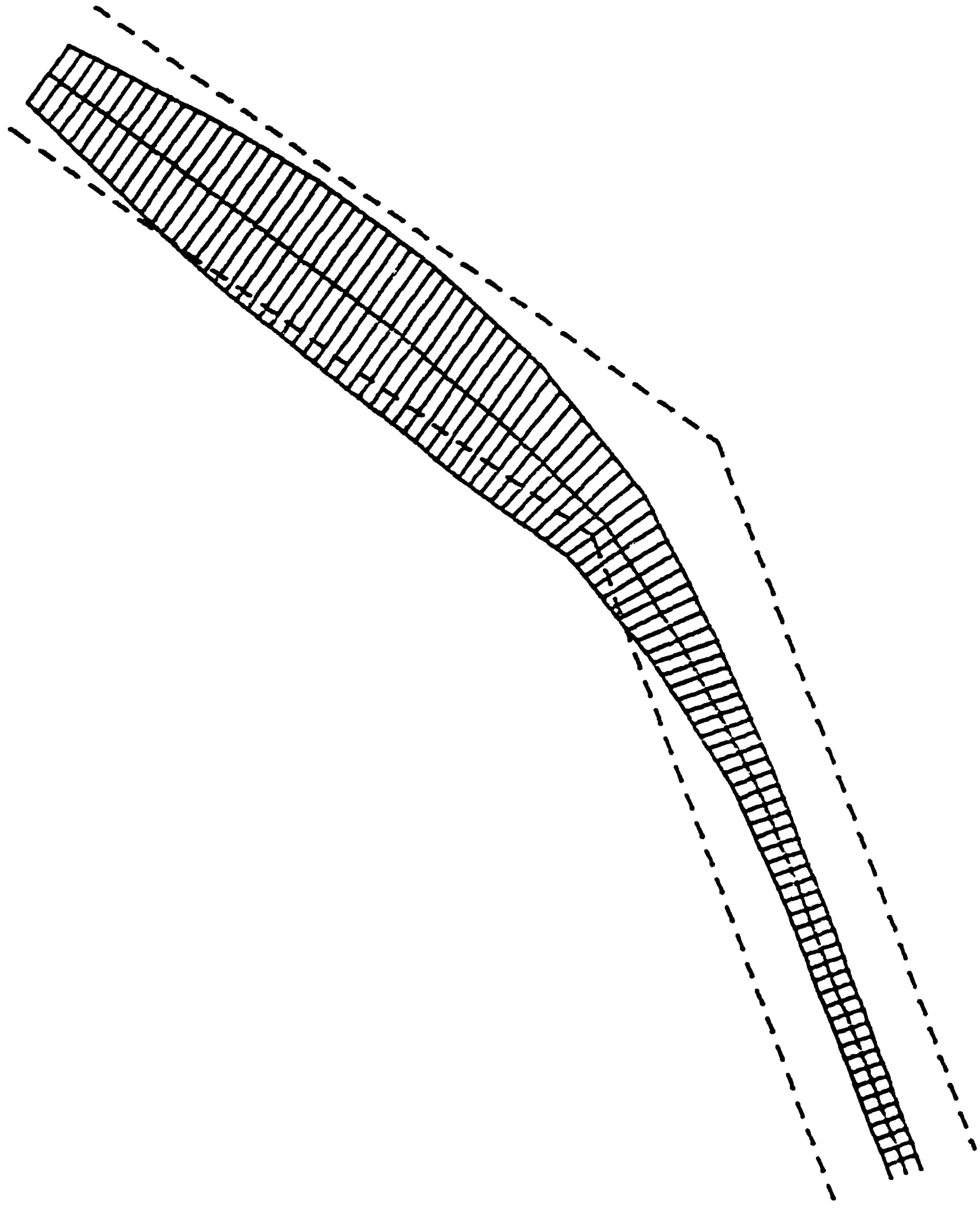


Figure D-1. All DIGITAL Displays

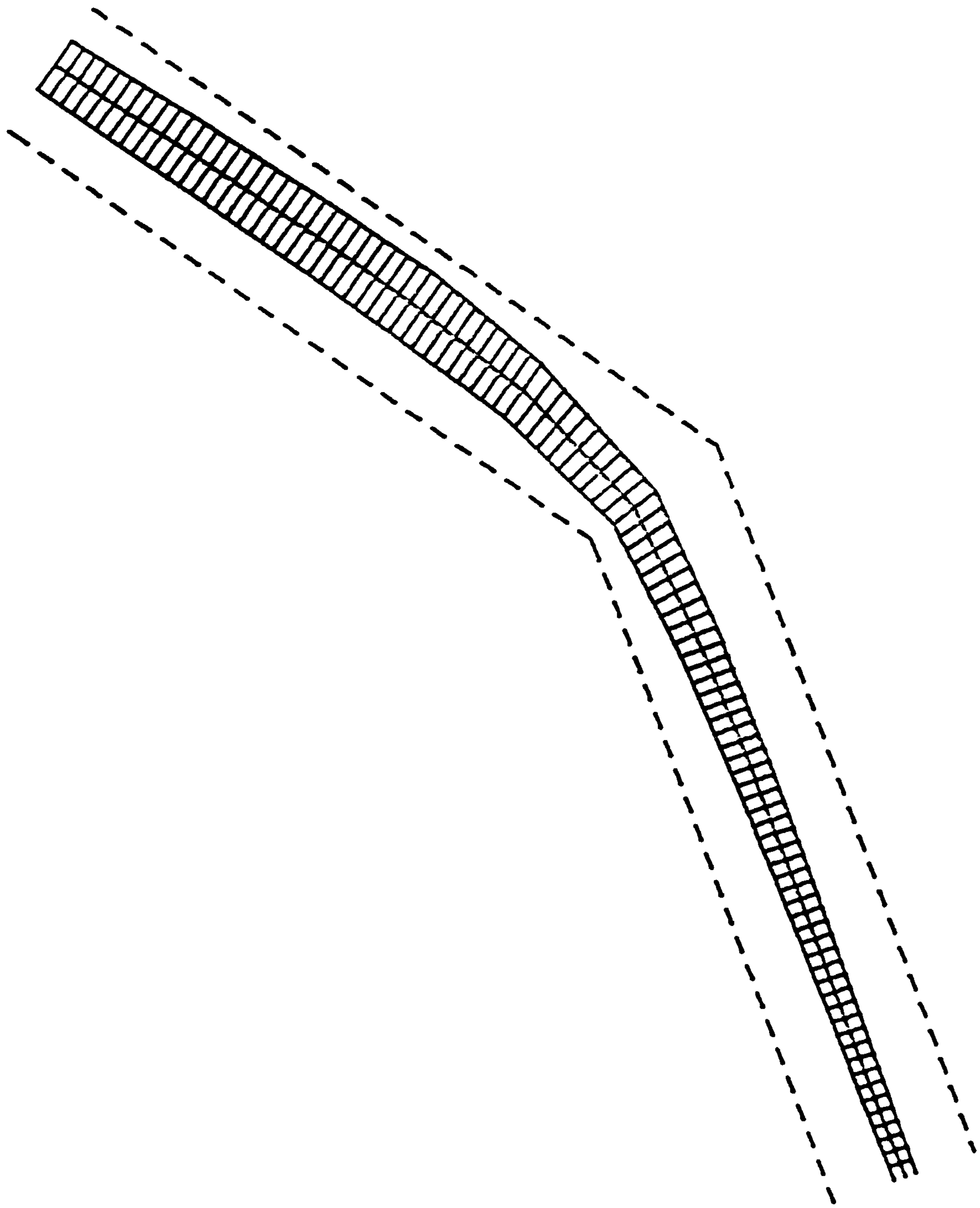


Figure D-2. All GRAPHIC Displays

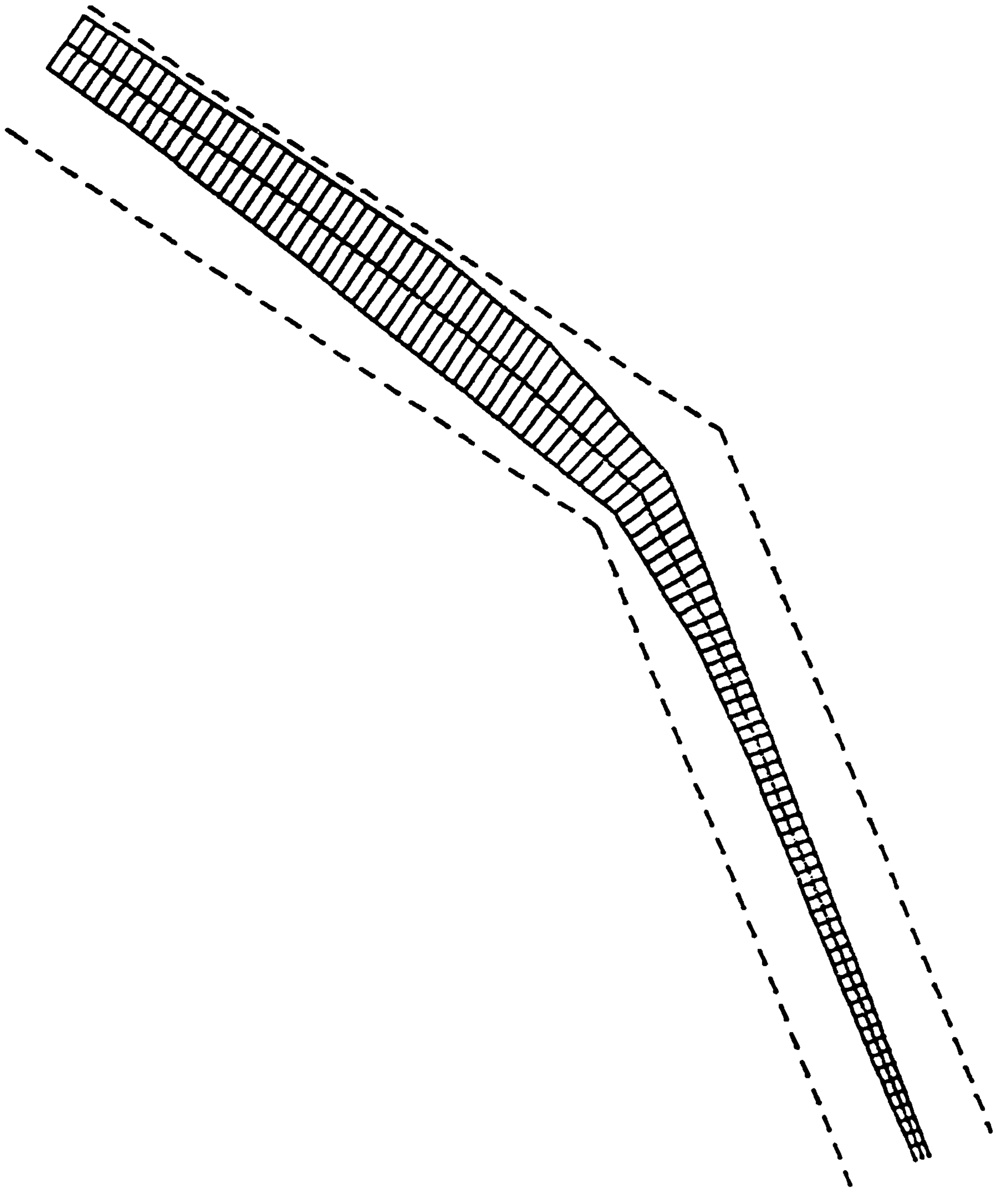


Figure D-3. All PERSPECTIVE Displays

Section D.2

DIGITAL DISPLAY VARIABLES

Data in this section allow comparison of trackkeeping performance between:

- No steering cues
- Course error
- Heading to steer
- Distance to leadline
- Time to leadline

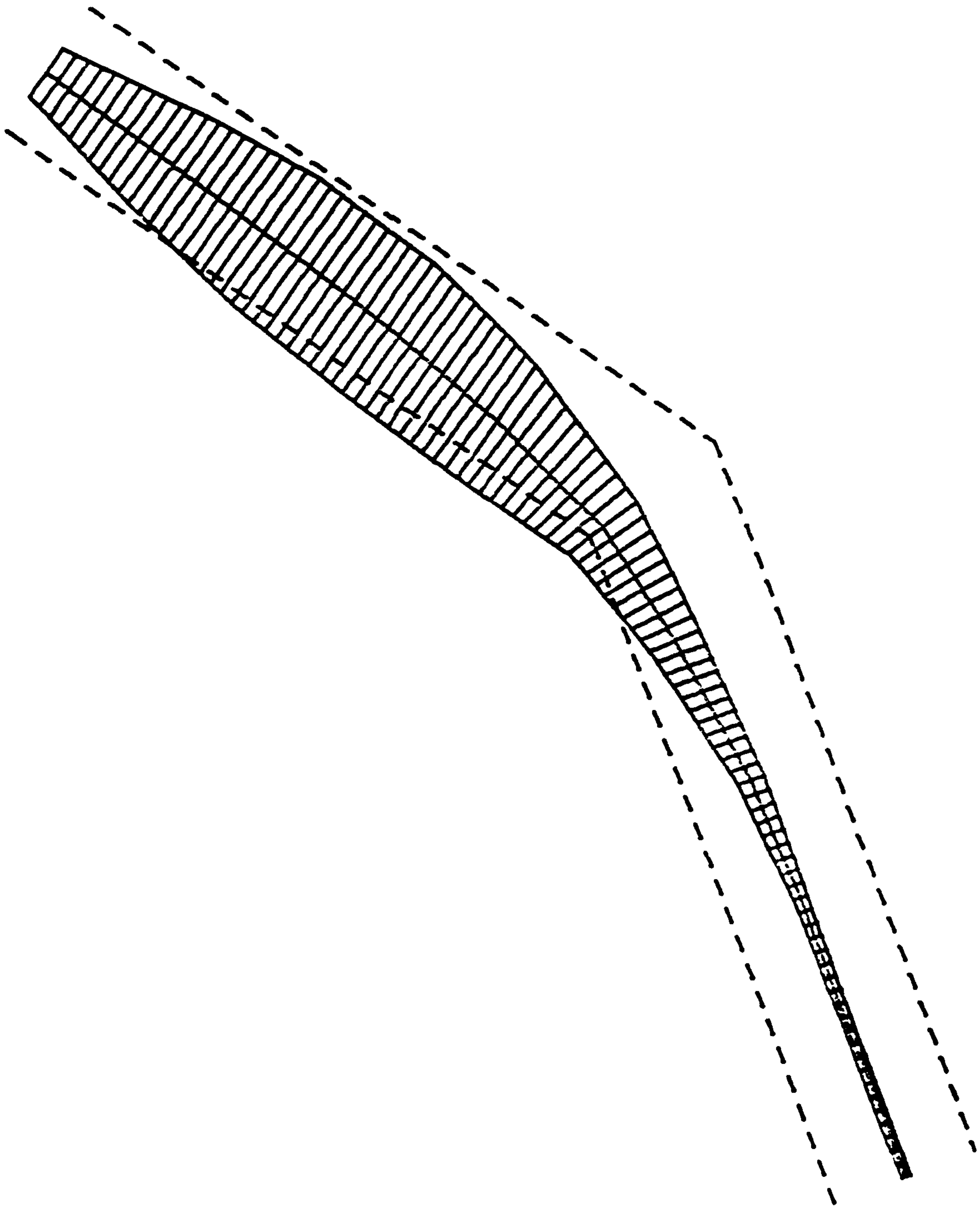


Figure D-4. DIGITAL Display, No Steering Cues

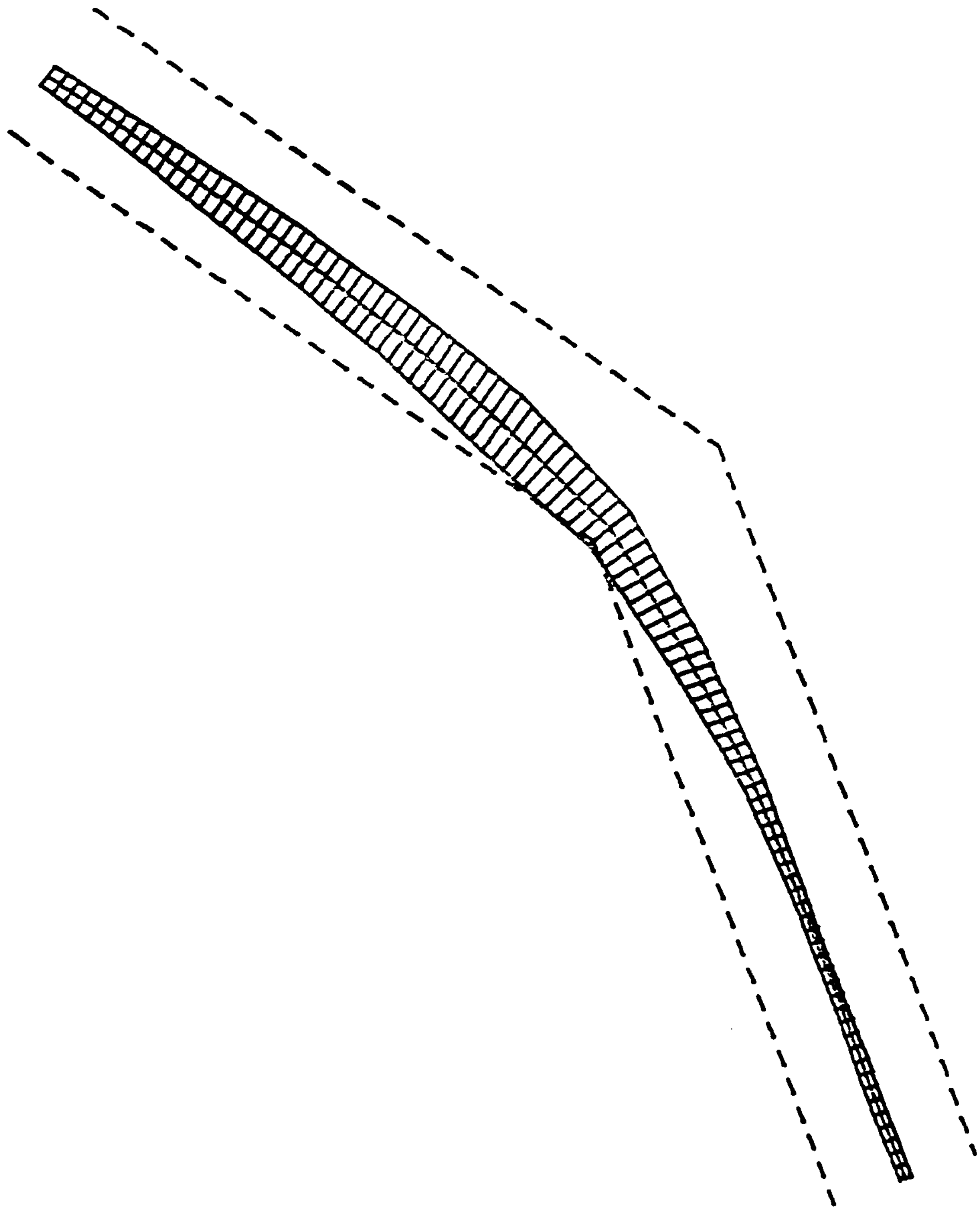


Figure D-5. DIGITAL Display, Course Error

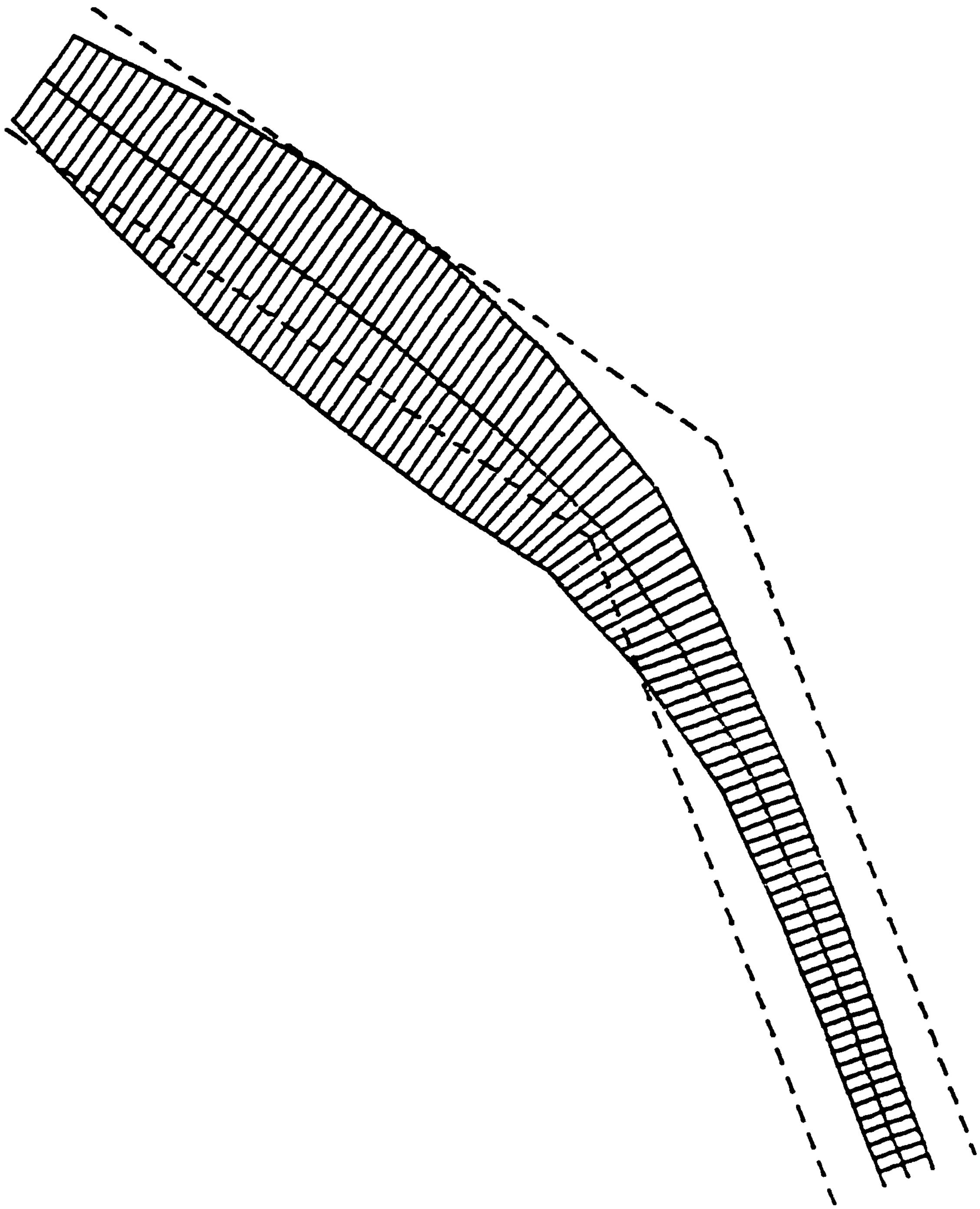


Figure D-6. DIGITAL Display, Heading to Steer

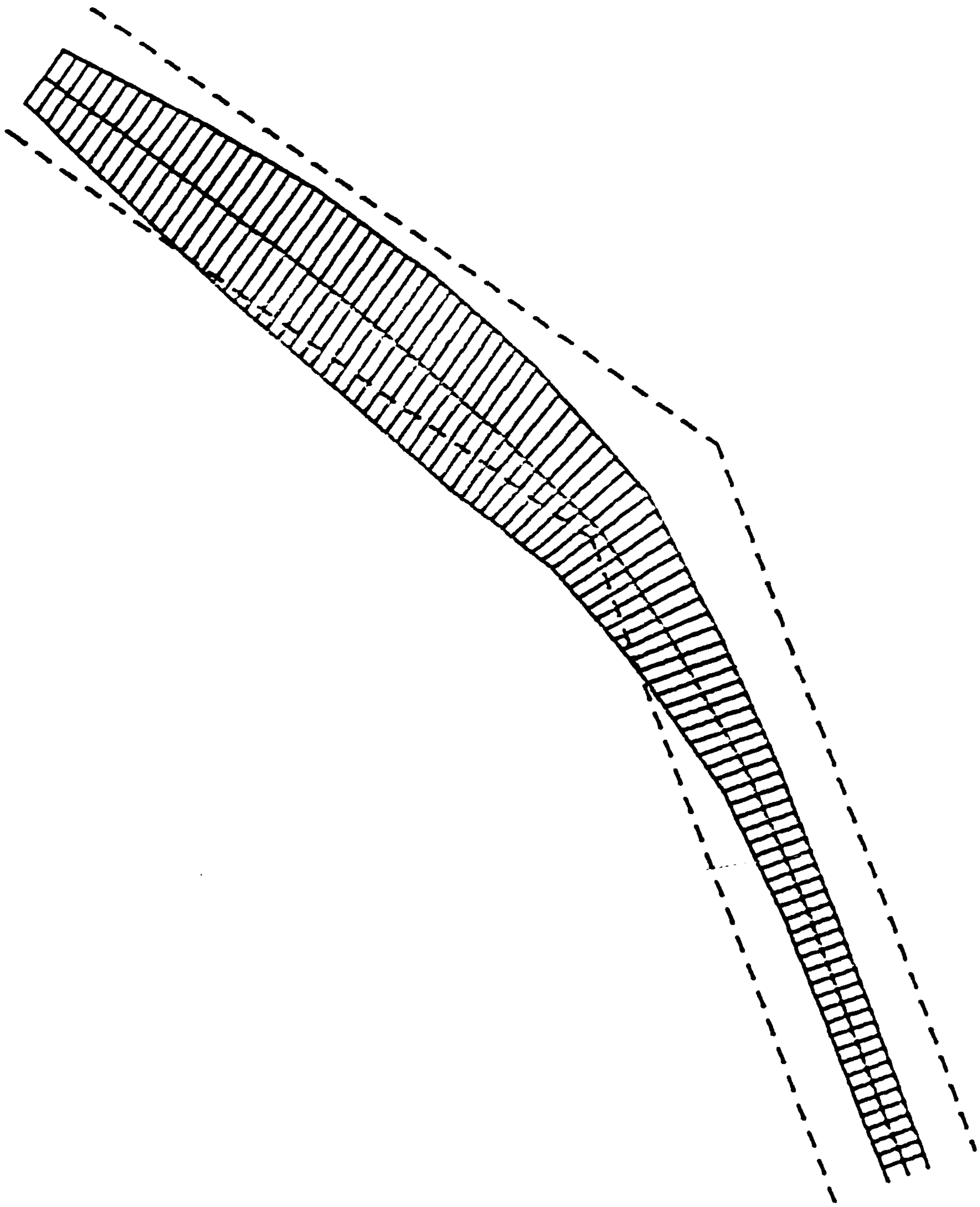


Figure D-7. DIGITAL Display, Distance to Leadline

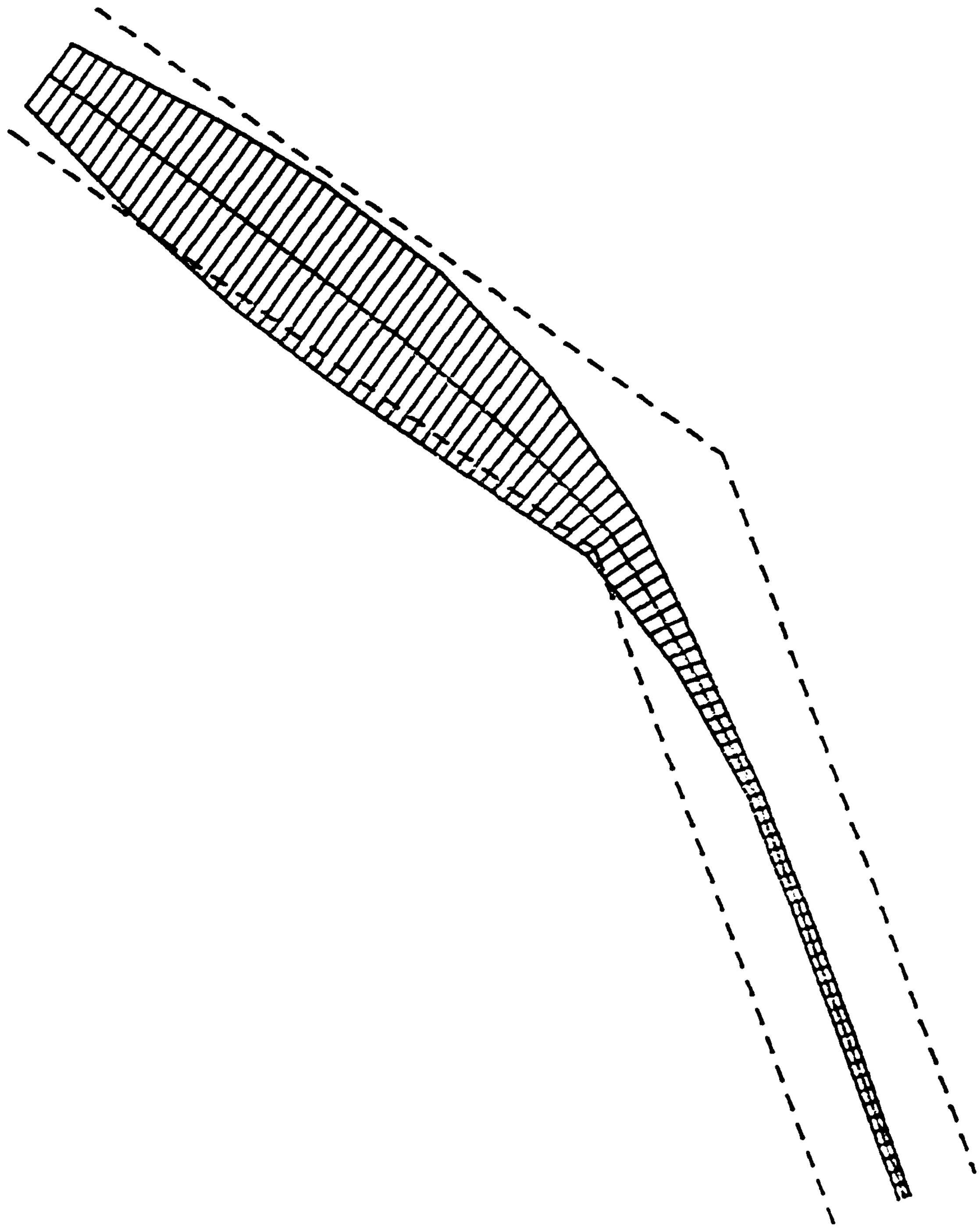


Figure D-8. DIGITAL Display, Time to Leadline

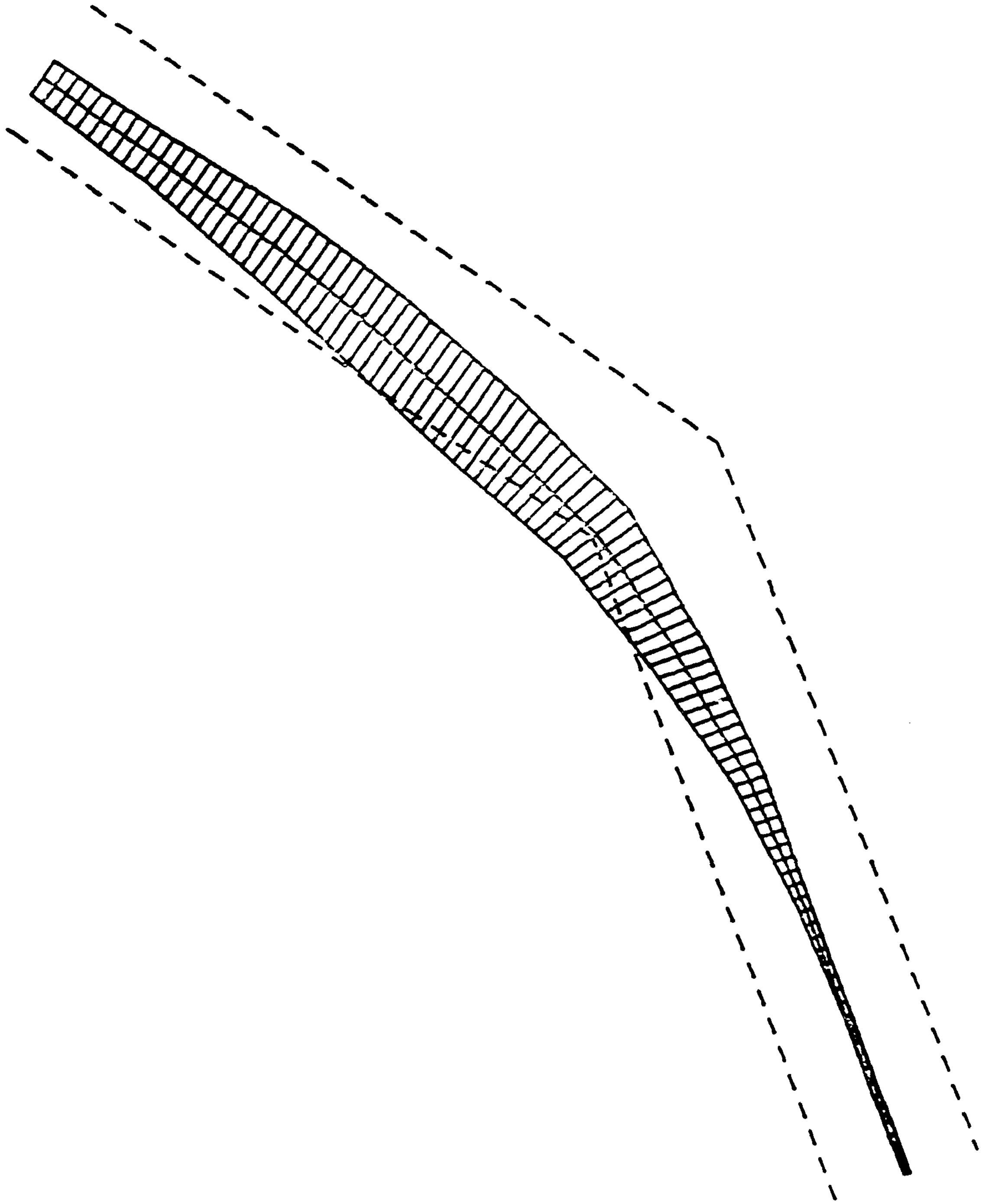


Figure D-9. DIGITAL Display, No Steering Cues, Distance to Leadline

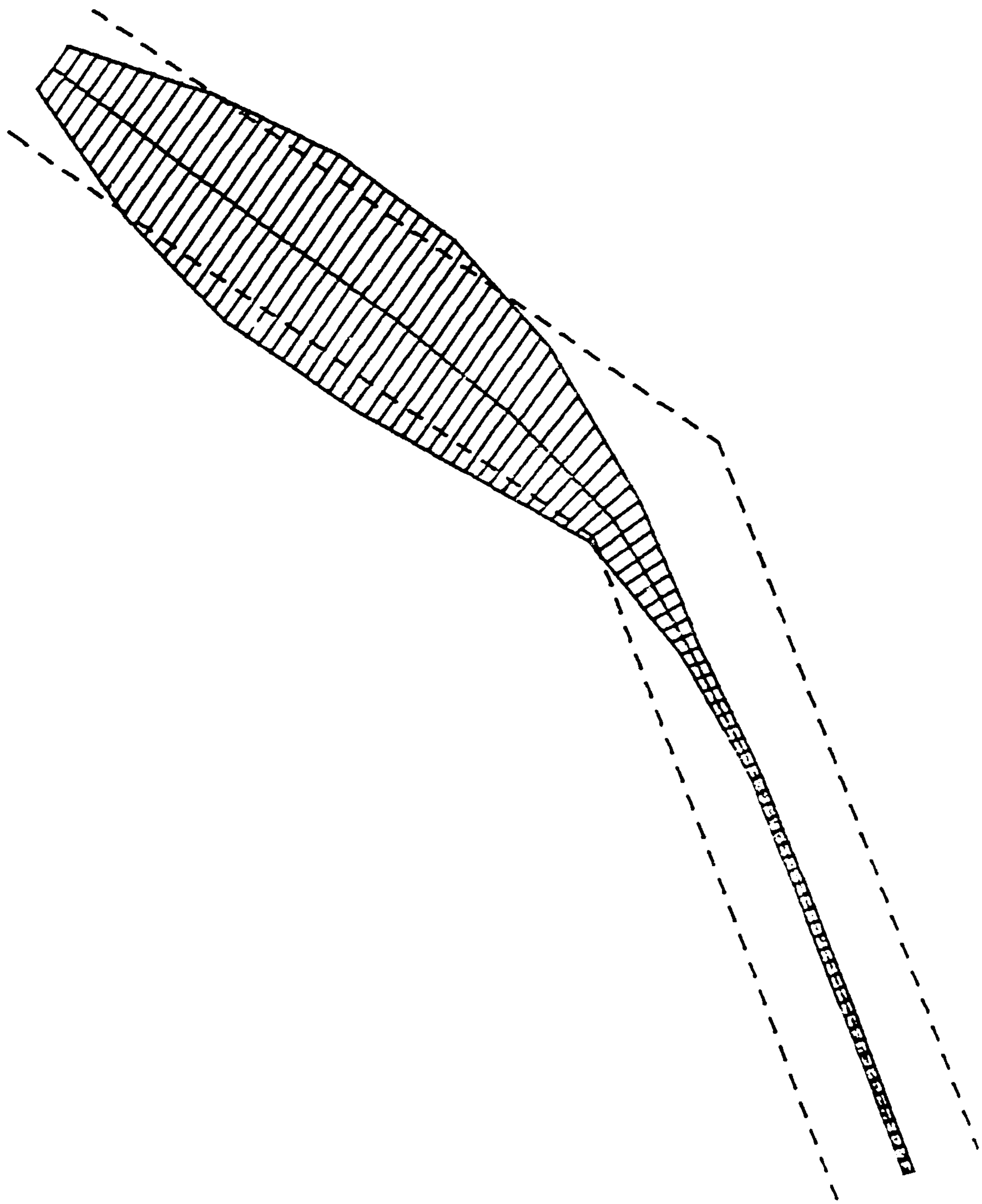
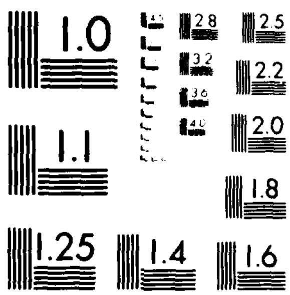


Figure D-10. DIGITAL Display, No Steering Cues, Time to Leadline

AD-A107 072 ECLECTECH ASSOCIATES INC NORTH STONINGTON CT F/G 17/7
SIMULATOR EVALUATION OF ELECTRONIC RADIO AIDS TO NAVIGATION DIS--ETC(U)
SEP 80 R B COOPER, K L MARINO DOT-CG-835285-A
UNCLASSIFIED EA-80-U-88 USCG-D-59-80 NL

2 of 2

END
DATE FILMED
12-81
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS [illegible]

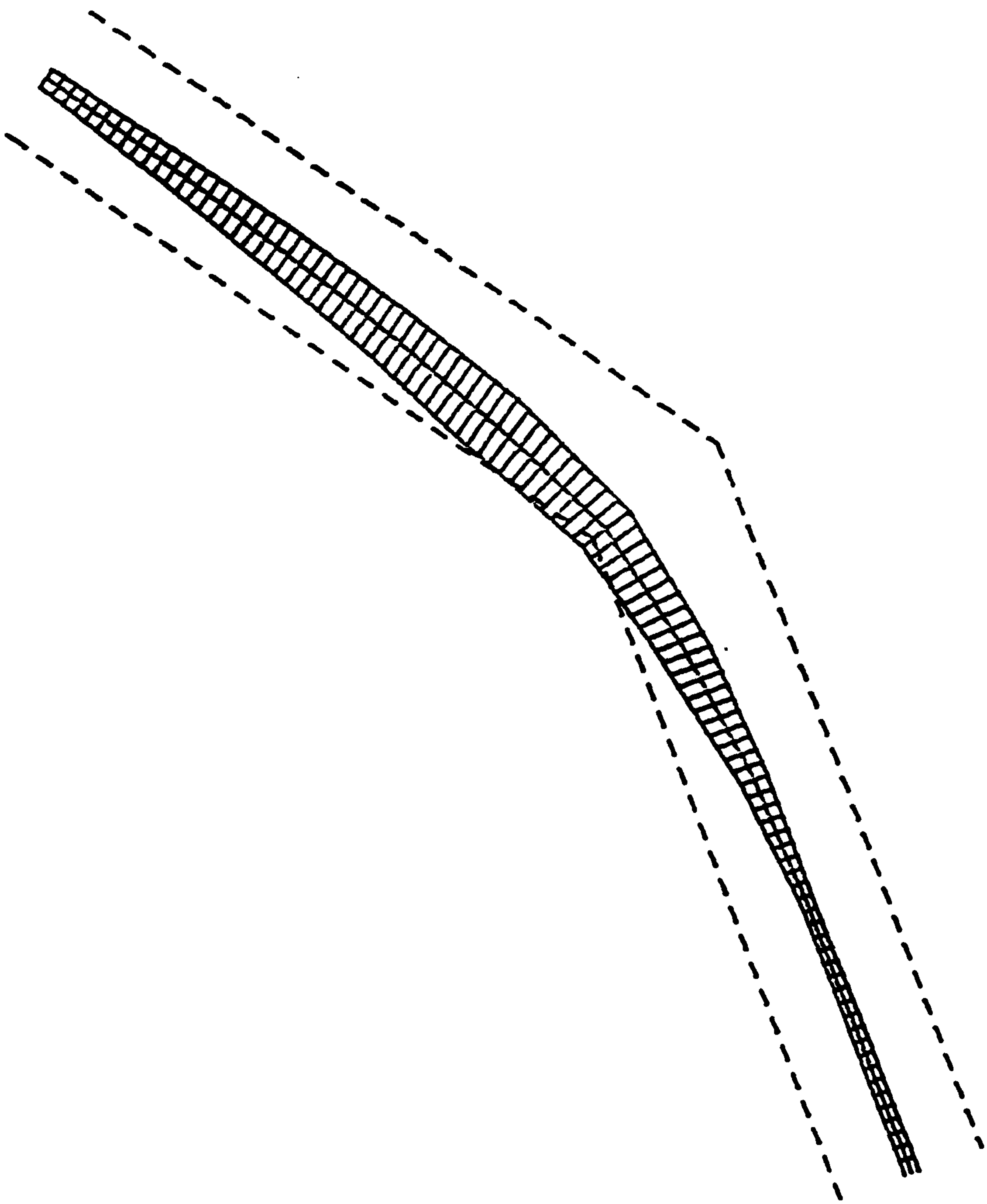


Figure D-11. DIGITAL Display, Course Error, Distance to Leadline

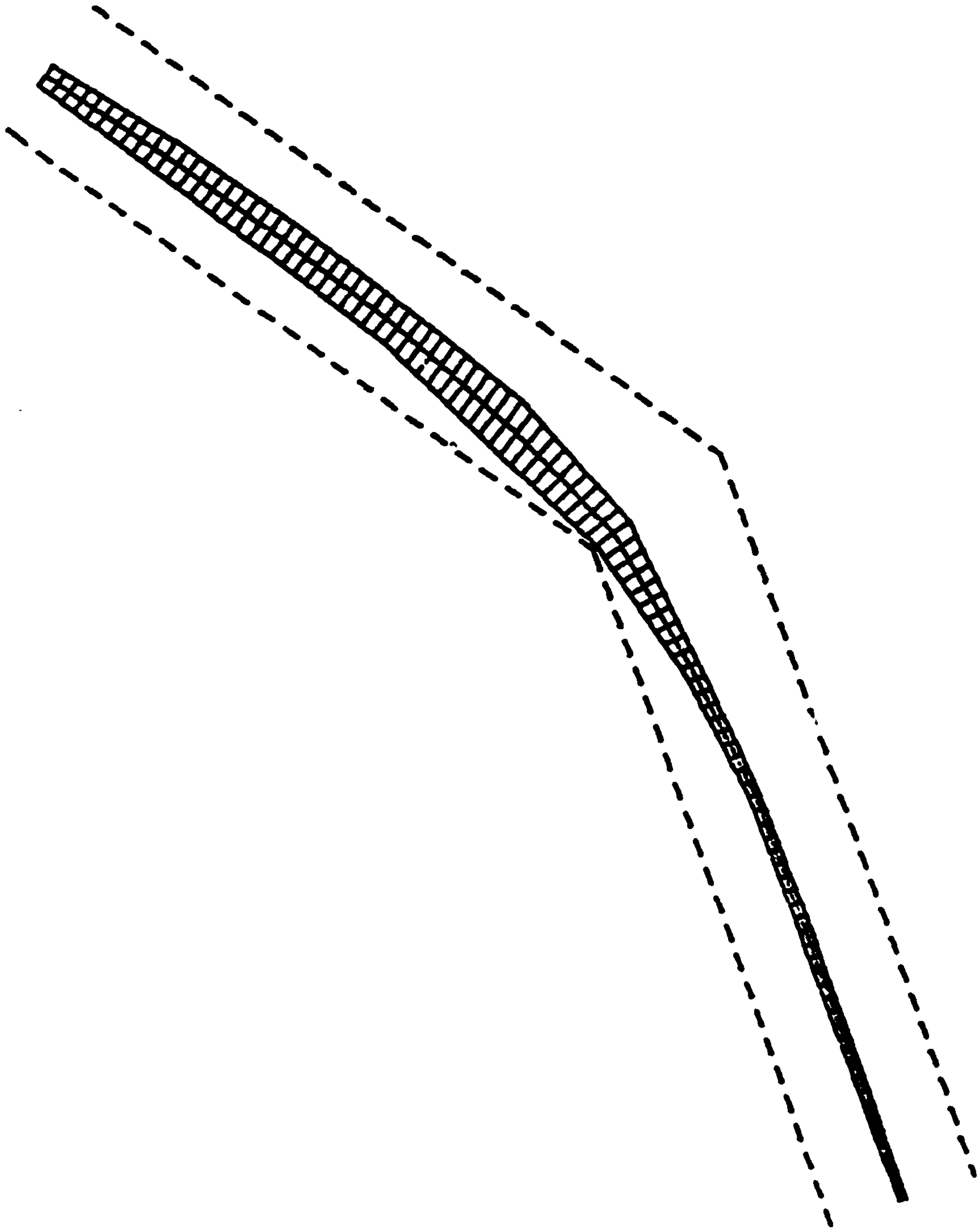


Figure D-12. DIGITAL Display, Course Error, Time to Leadline

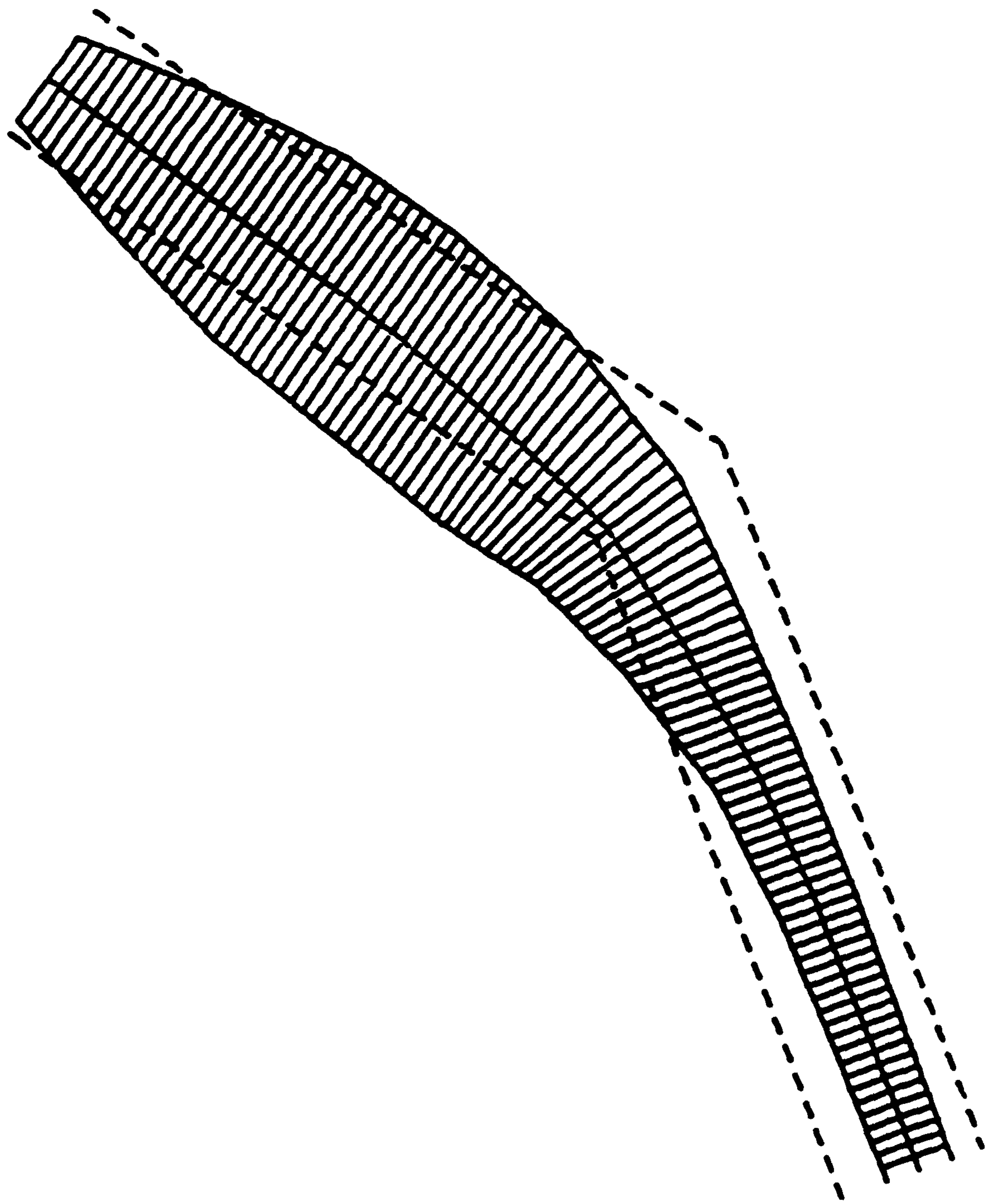


Figure D-13. DIGITAL Display, Heading to Steer, Distance to Leadline

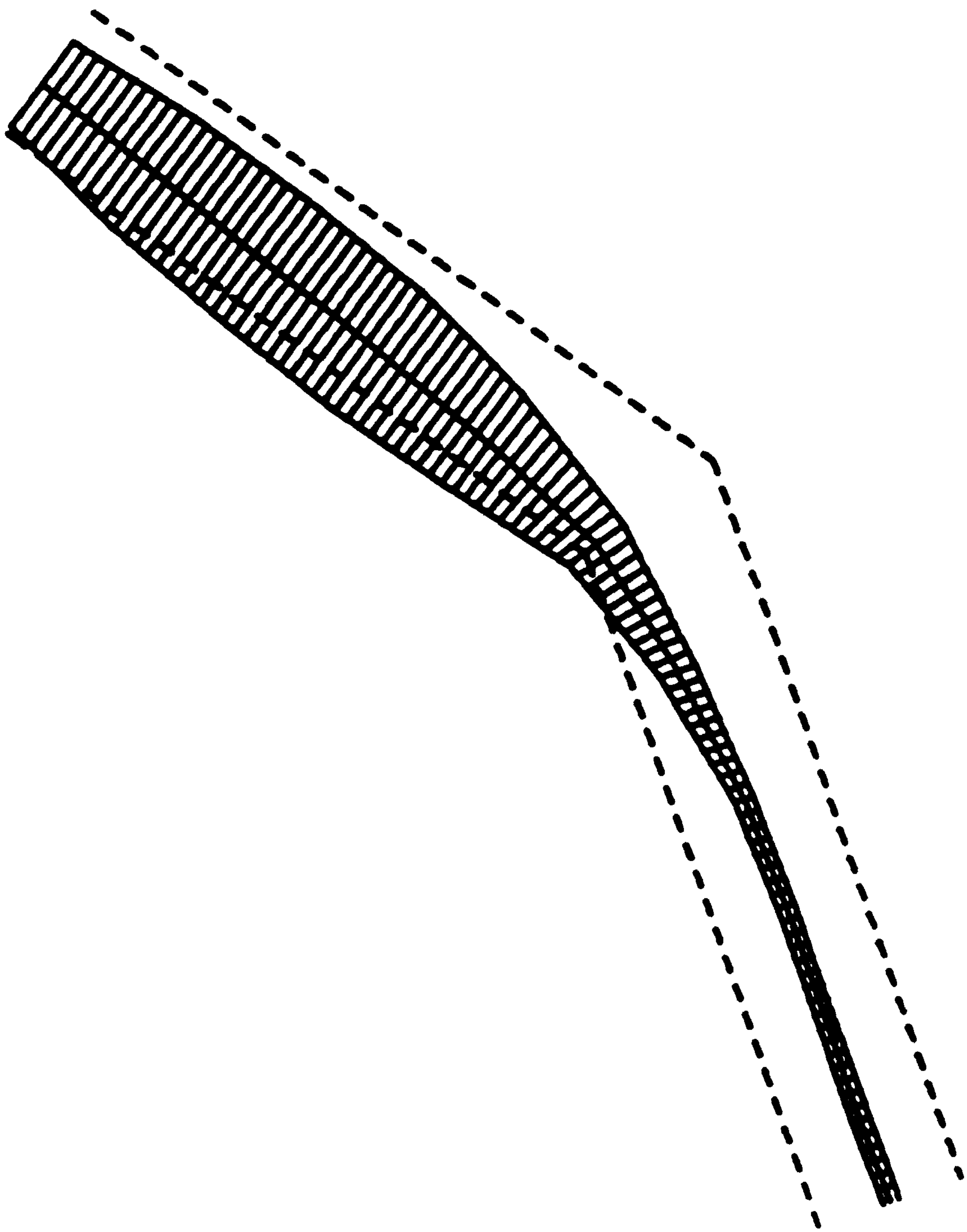


Figure D-14. DIGITAL Display, Heading to Steer, Time to Leadline

Section D.3

GRAPHIC DISPLAY VARIABLES

Data in this section allow comparison of trackkeeping performance between:

- True motion
- Relative motion
- Track up
- Head up

- Heading vector
- Course vector

- Scaled ship image
- Symbolic ship image

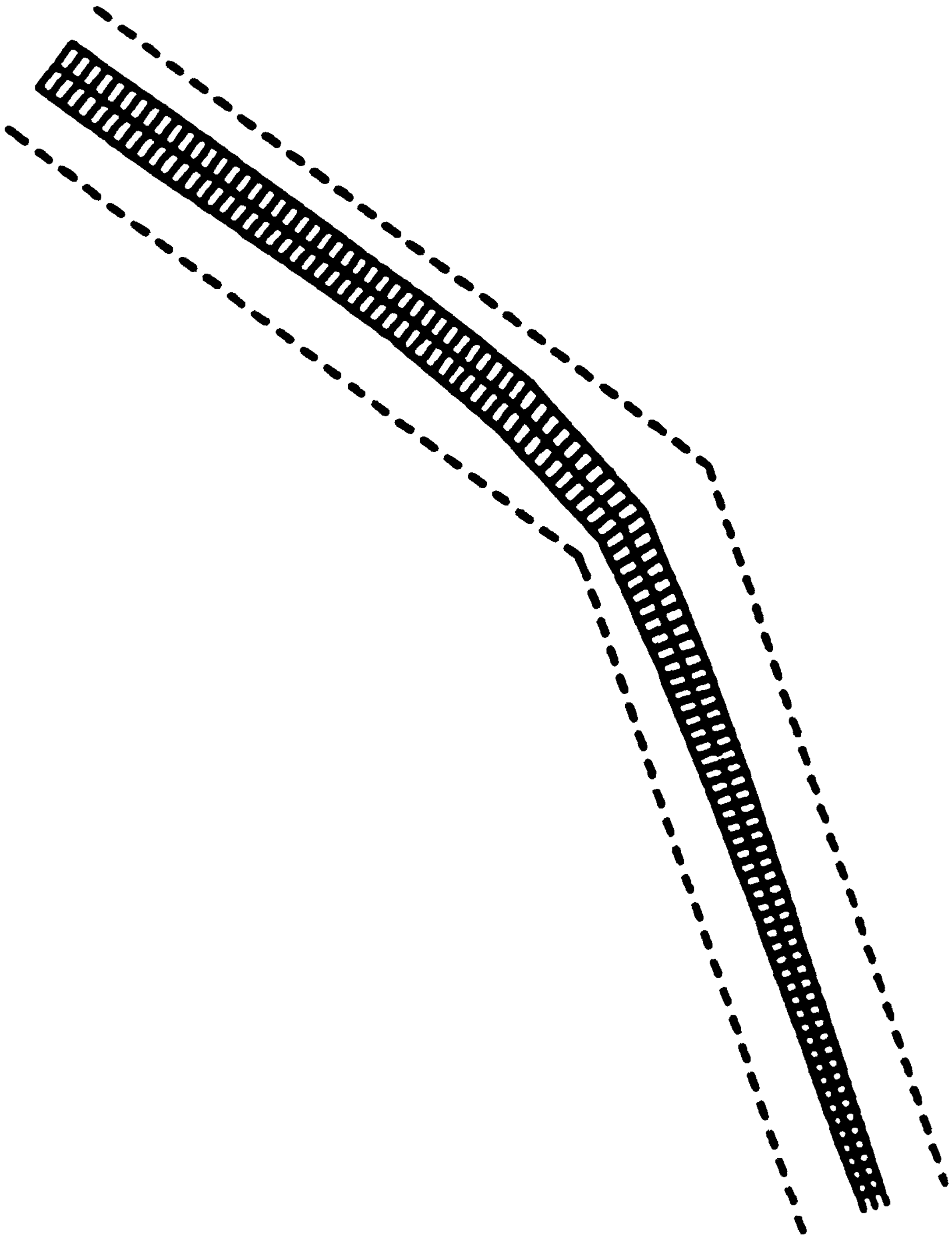


Figure 3-15. GRAPHIC Display, True Motion, Track-Up

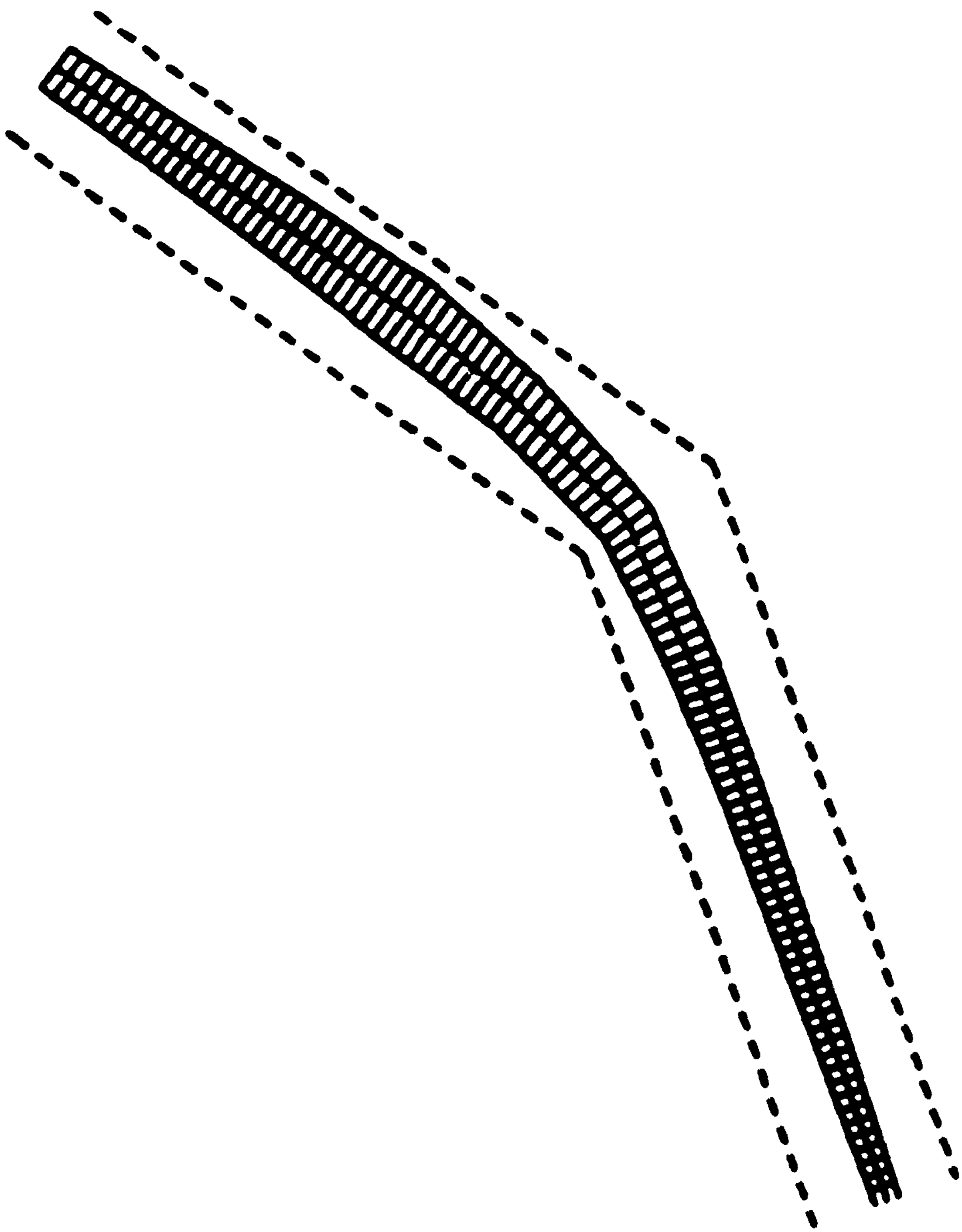


Figure 3-16. [illegible] Display, Relative Motion, Track-up

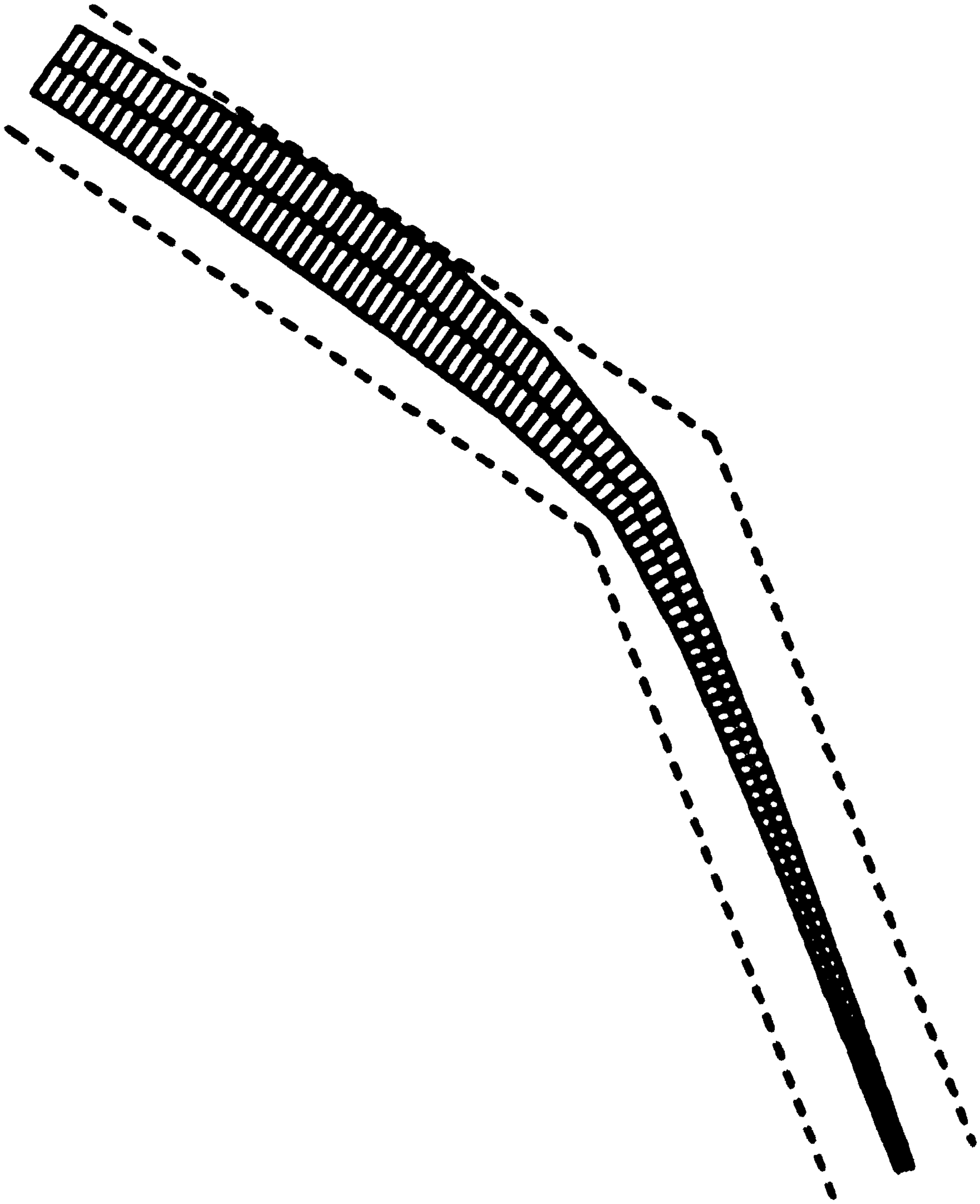


Figure 3-[illegible]. Channel Display, Relative Motion, Head-Up

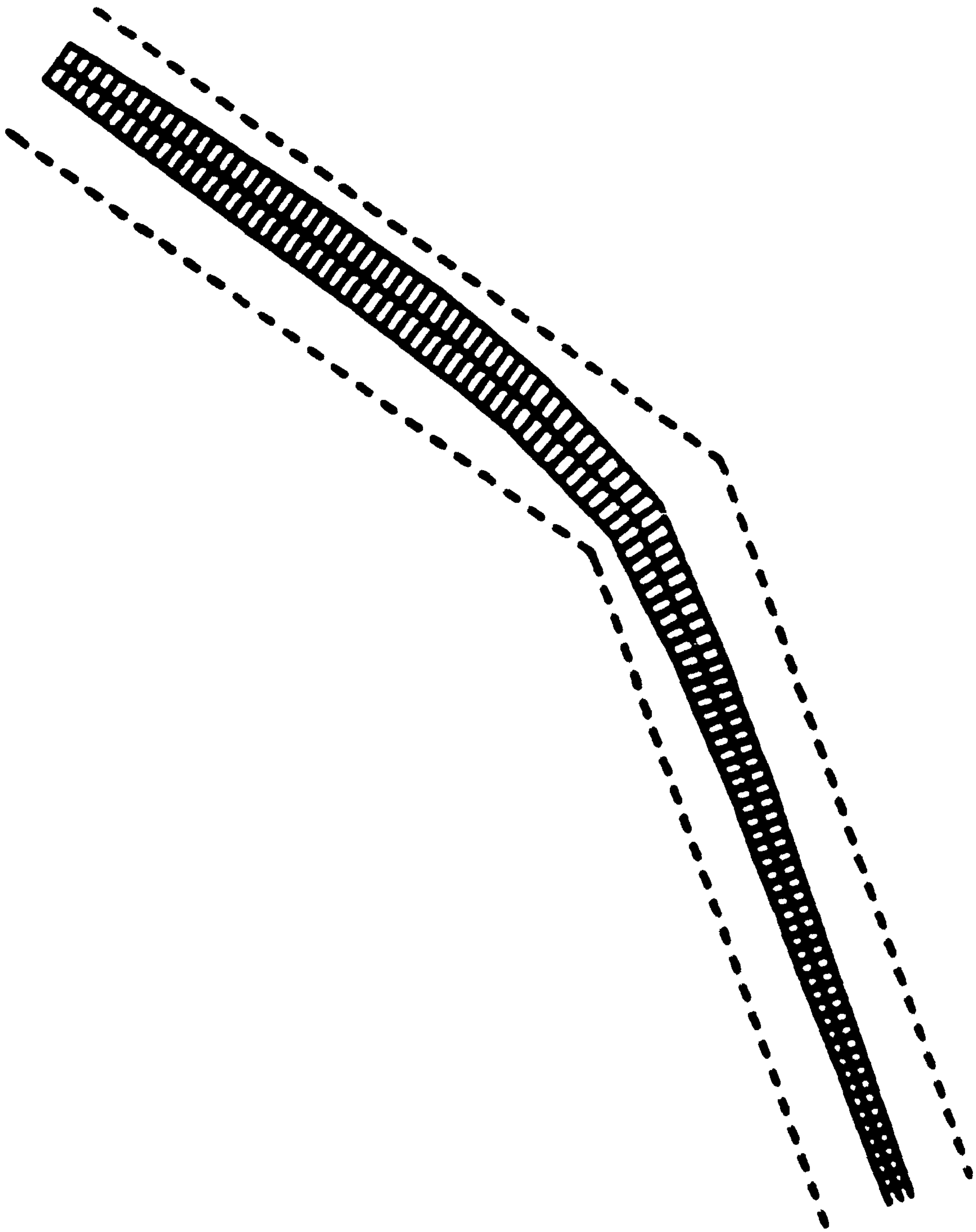


Figure 3-18 Channel Display, Heading Vector

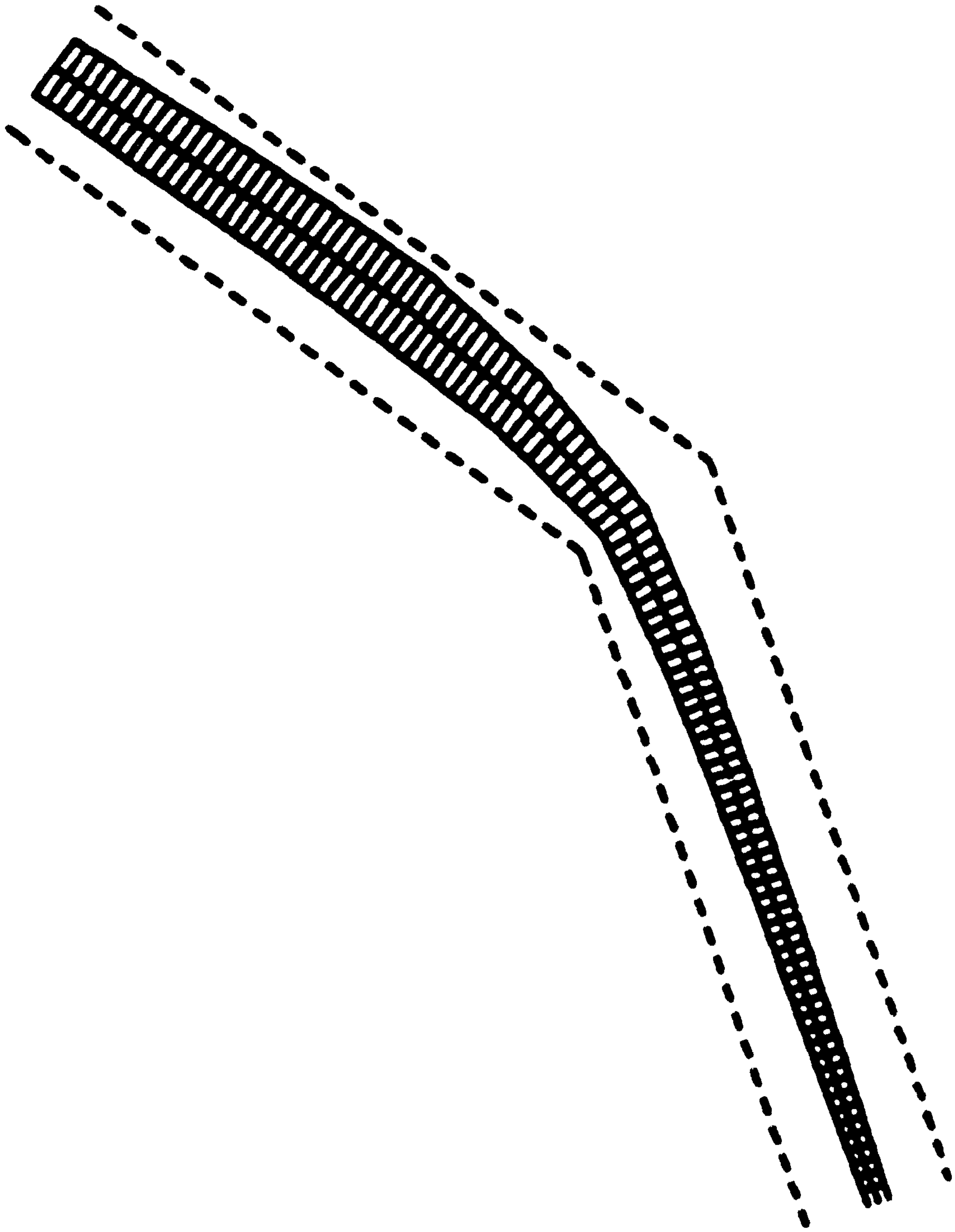


Figure 3-19. Channel Display, Course Vector

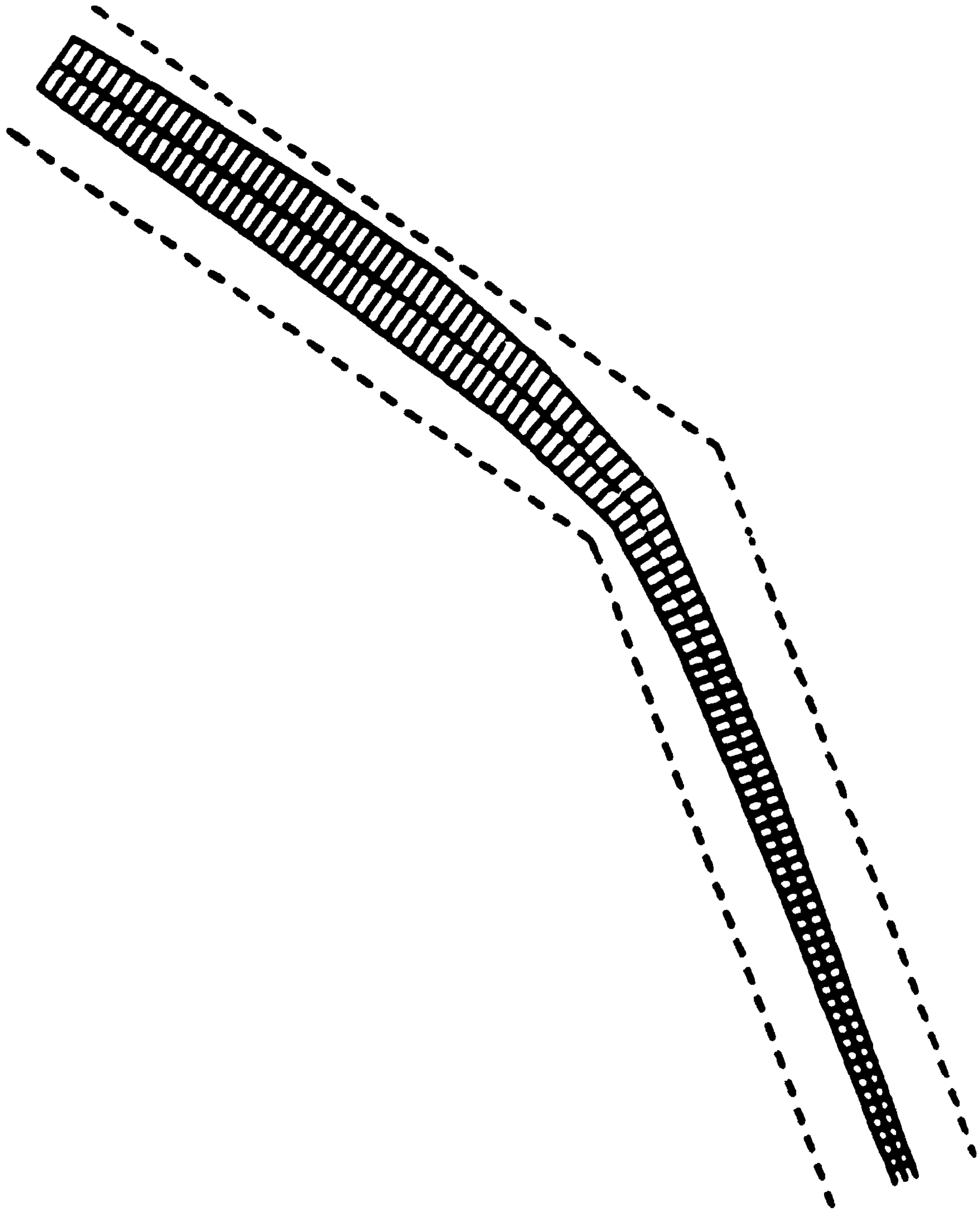


Figure 3-22. [illegible] Display, Scaled Chip Image

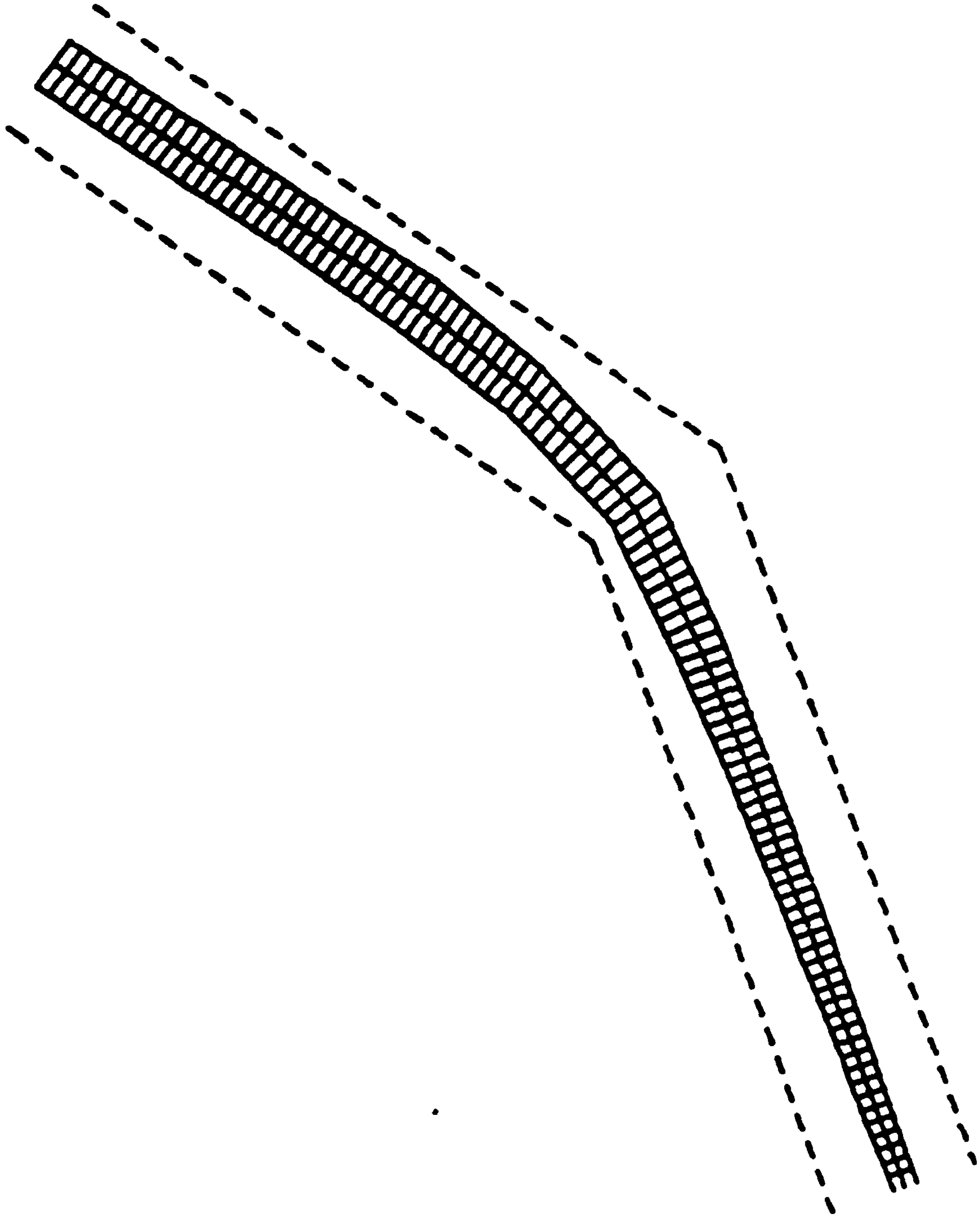


Figure D-21. GRAPHIC Display, Symbolic Ship Image

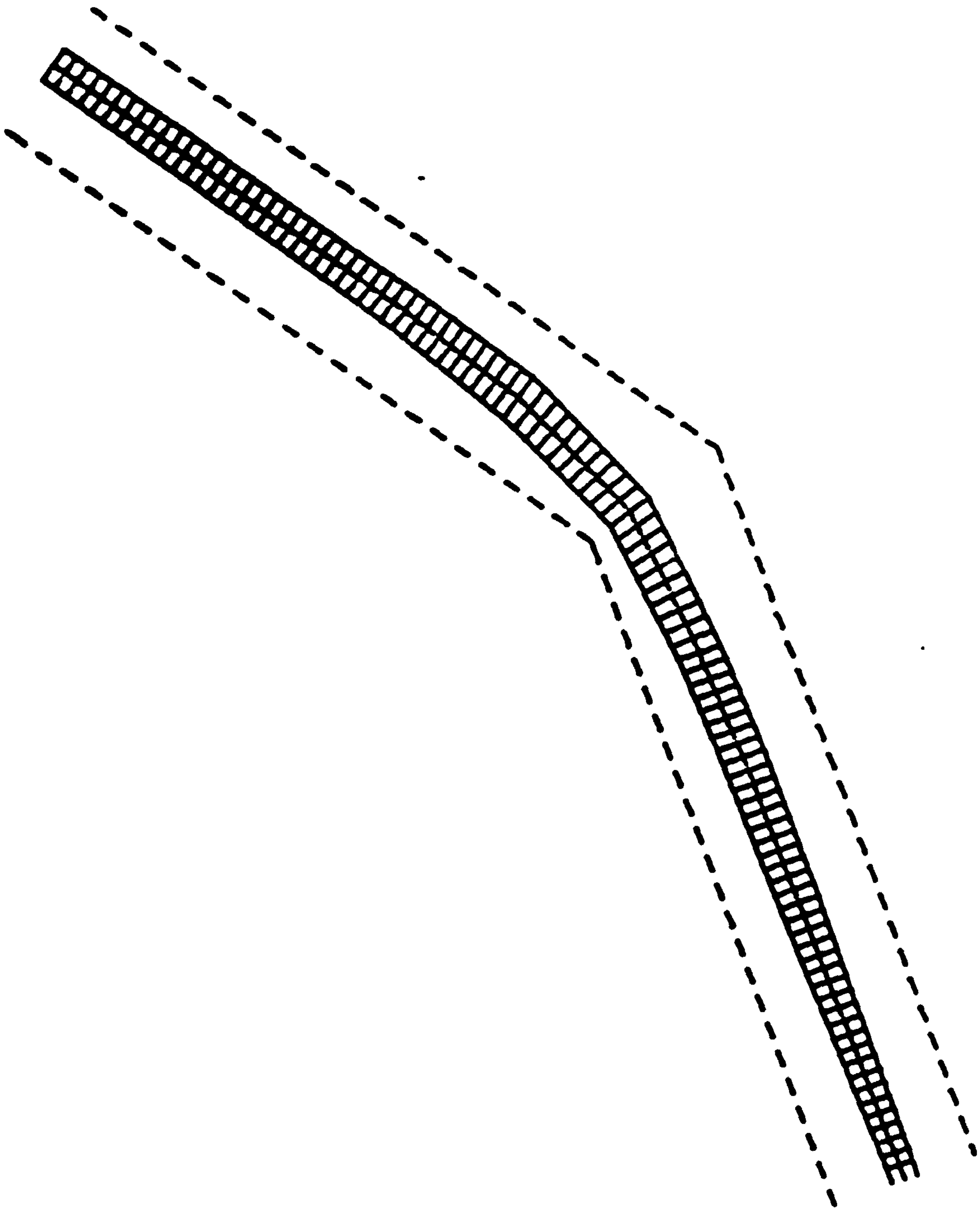


Figure 3-22. GRAPHIC Display, True Motion, Track-Up, Heading Vector, Scaled Ship Image

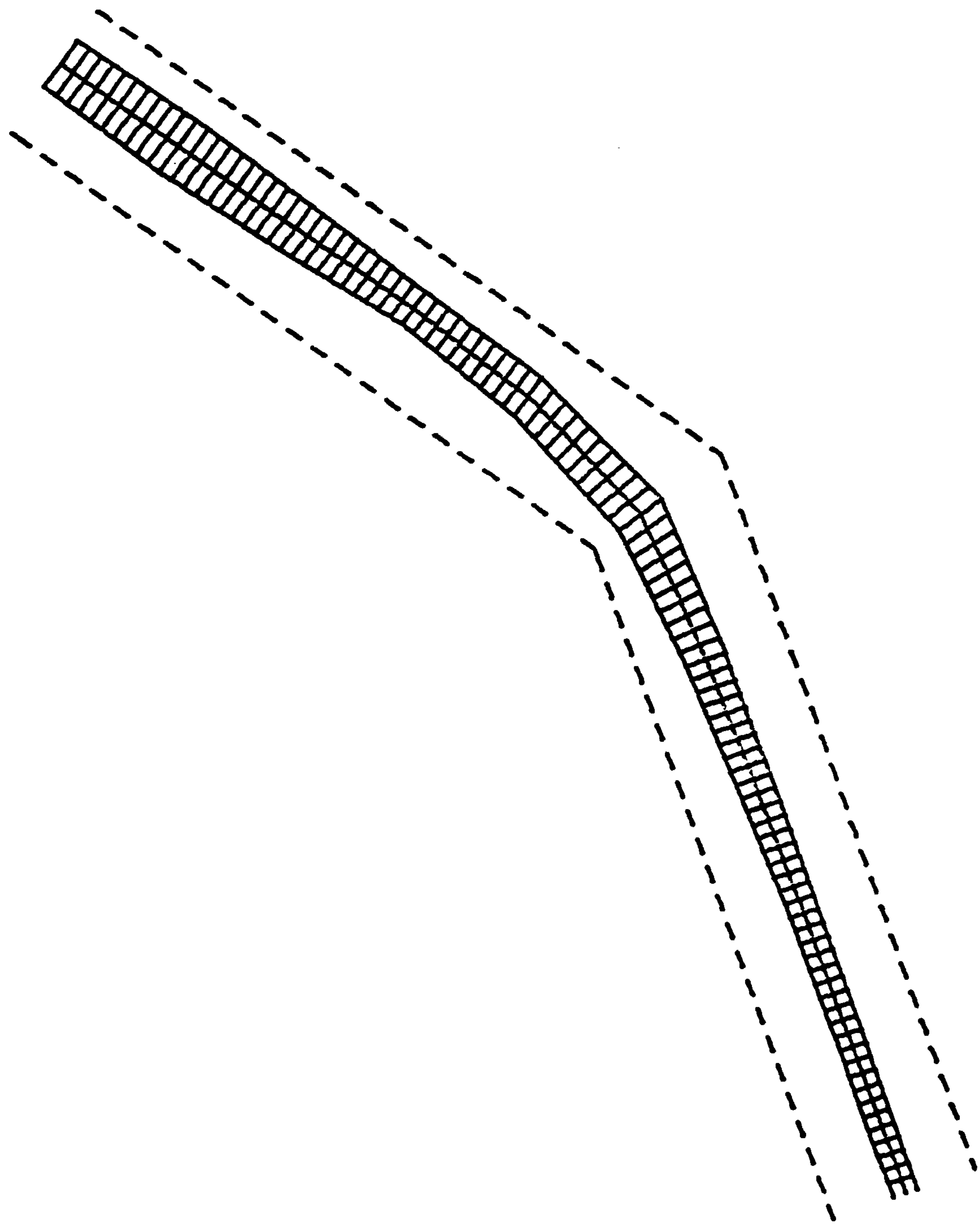


Figure D-23. GRAPHIC Display, True Motion, Track-Up, Heading Vector, Symbolic Ship Image

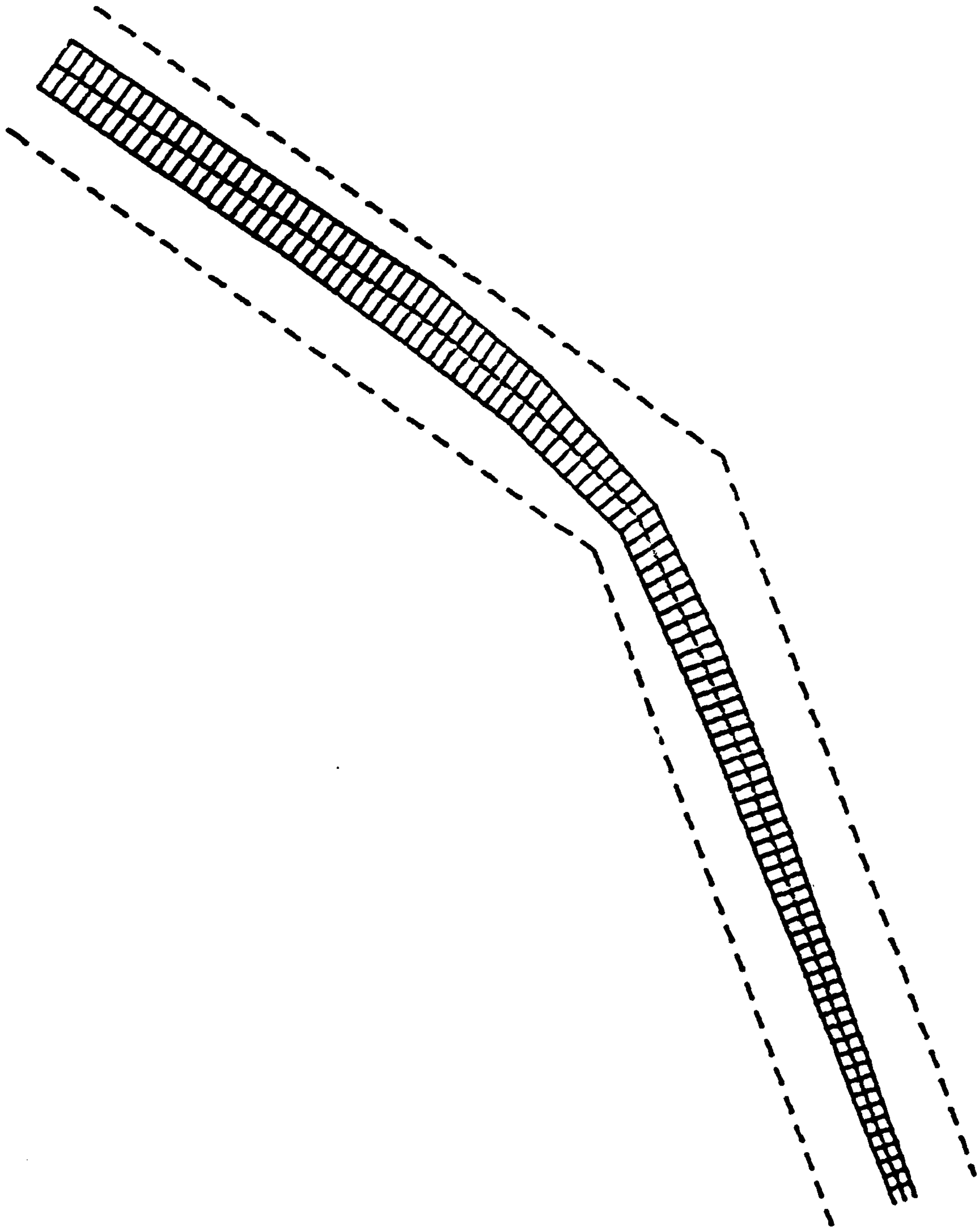


Figure D-24. GRAPHIC Display, True Motion, Track-Up, Course Vector, Scaled Ship Image

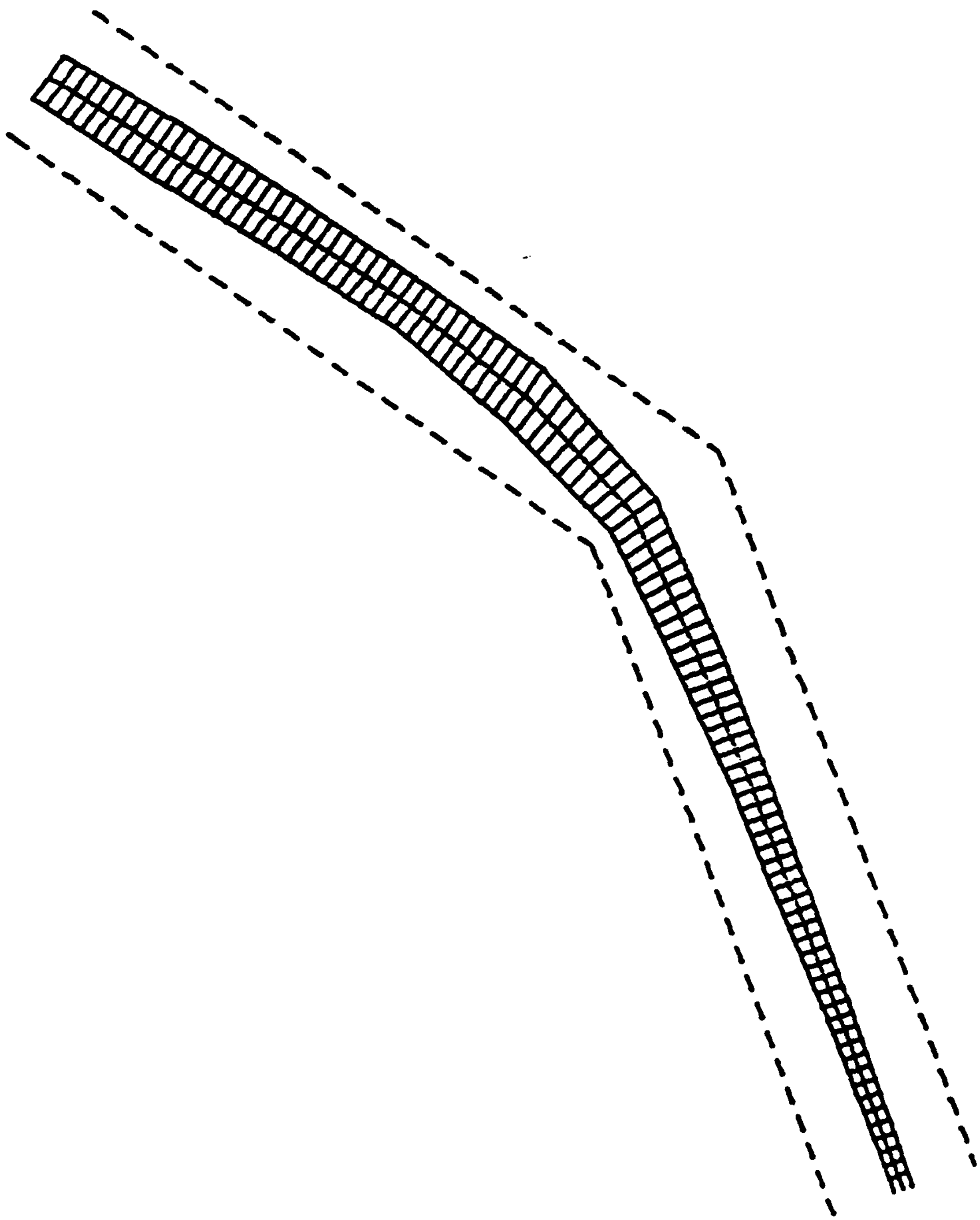


Figure D-25. GRAPHIC Display, True Motion, Track-Up, Course Vector, Symbolic Ship Image

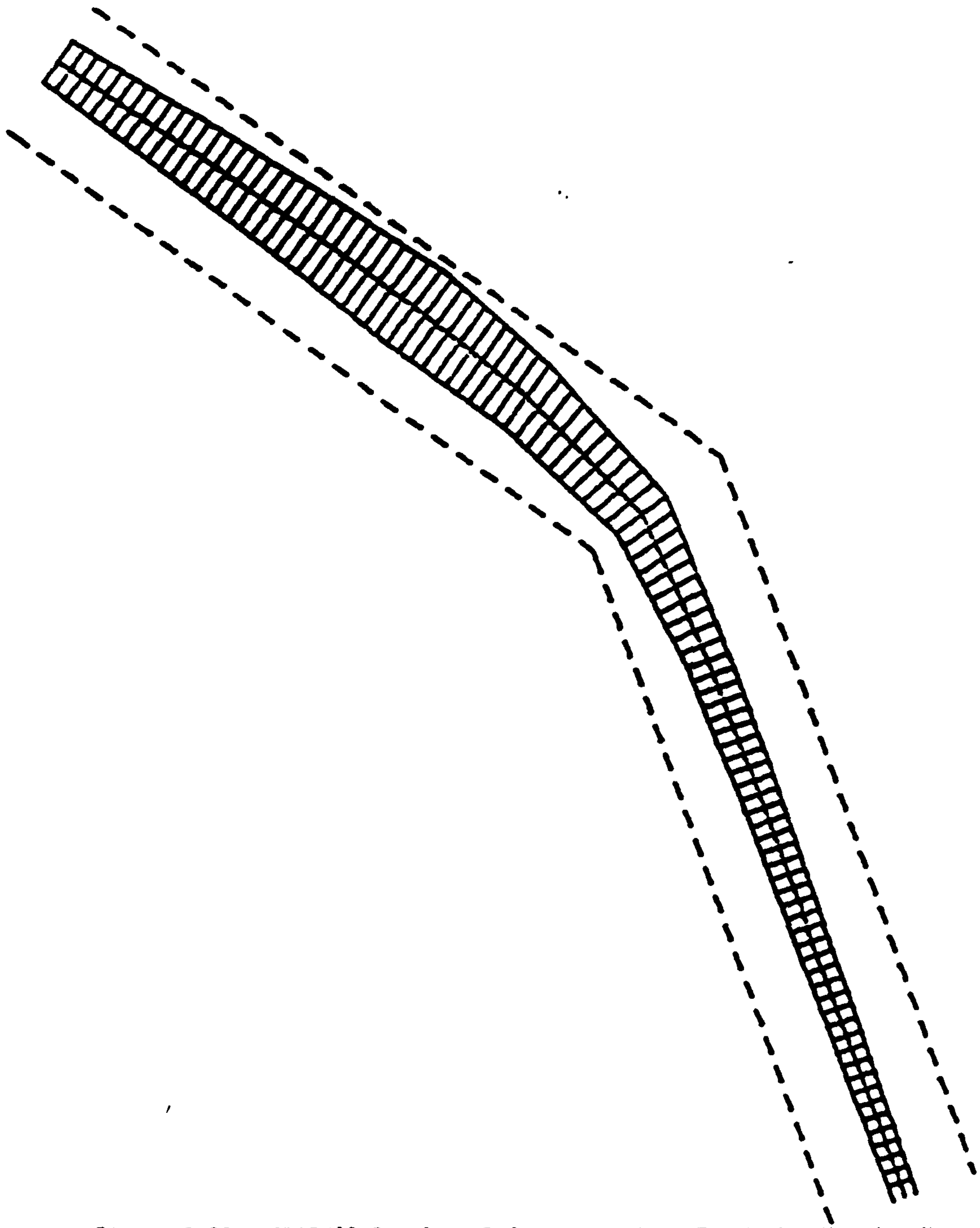


Figure D-26. GRAPHIC Display, Relative Motion, Track-Up, Heading Vector, Scaled Ship Image

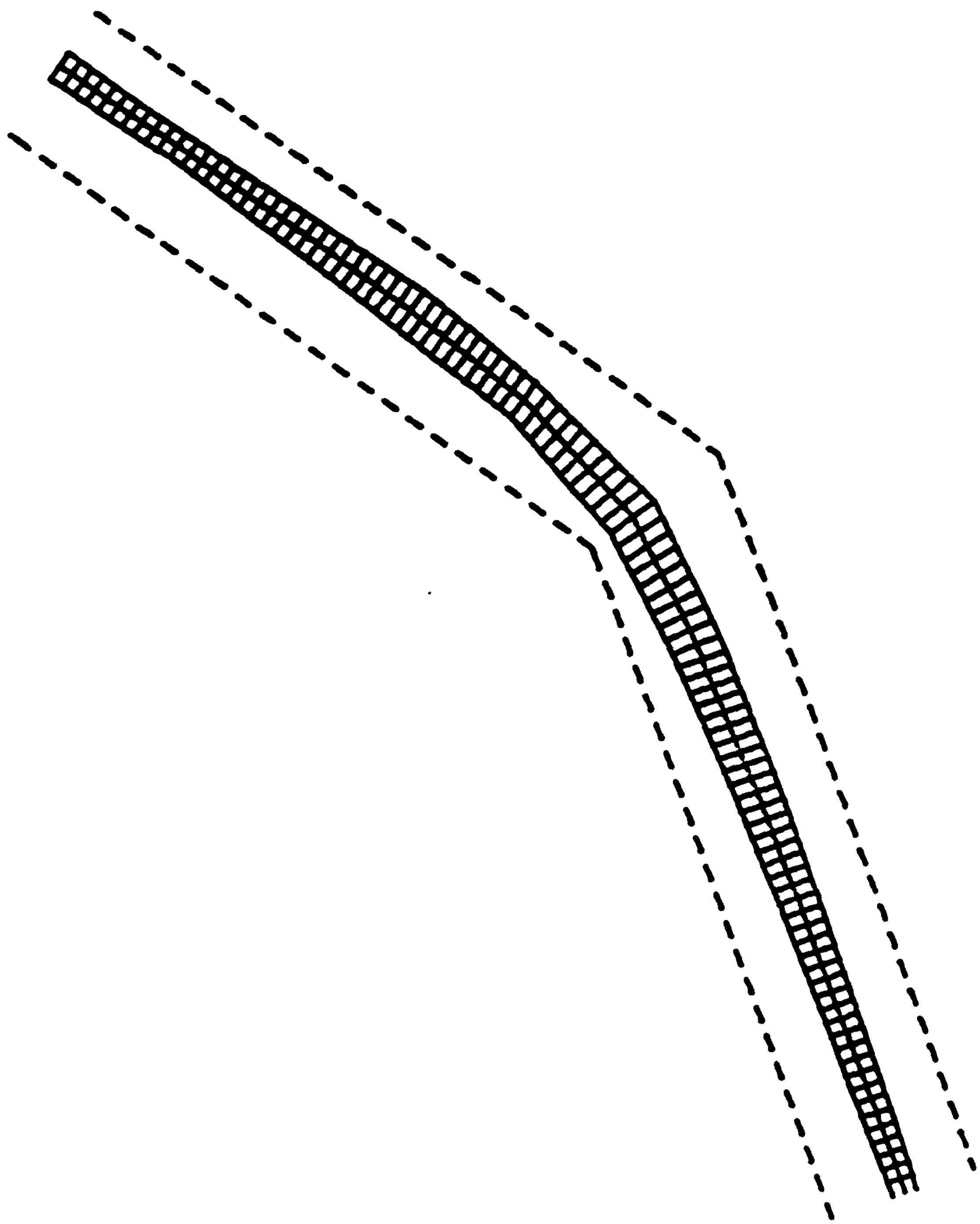


Figure D-27. GRAPHIC Display, Relative Motion, Track-Up, Heading Vector, Symbolic Ship Image

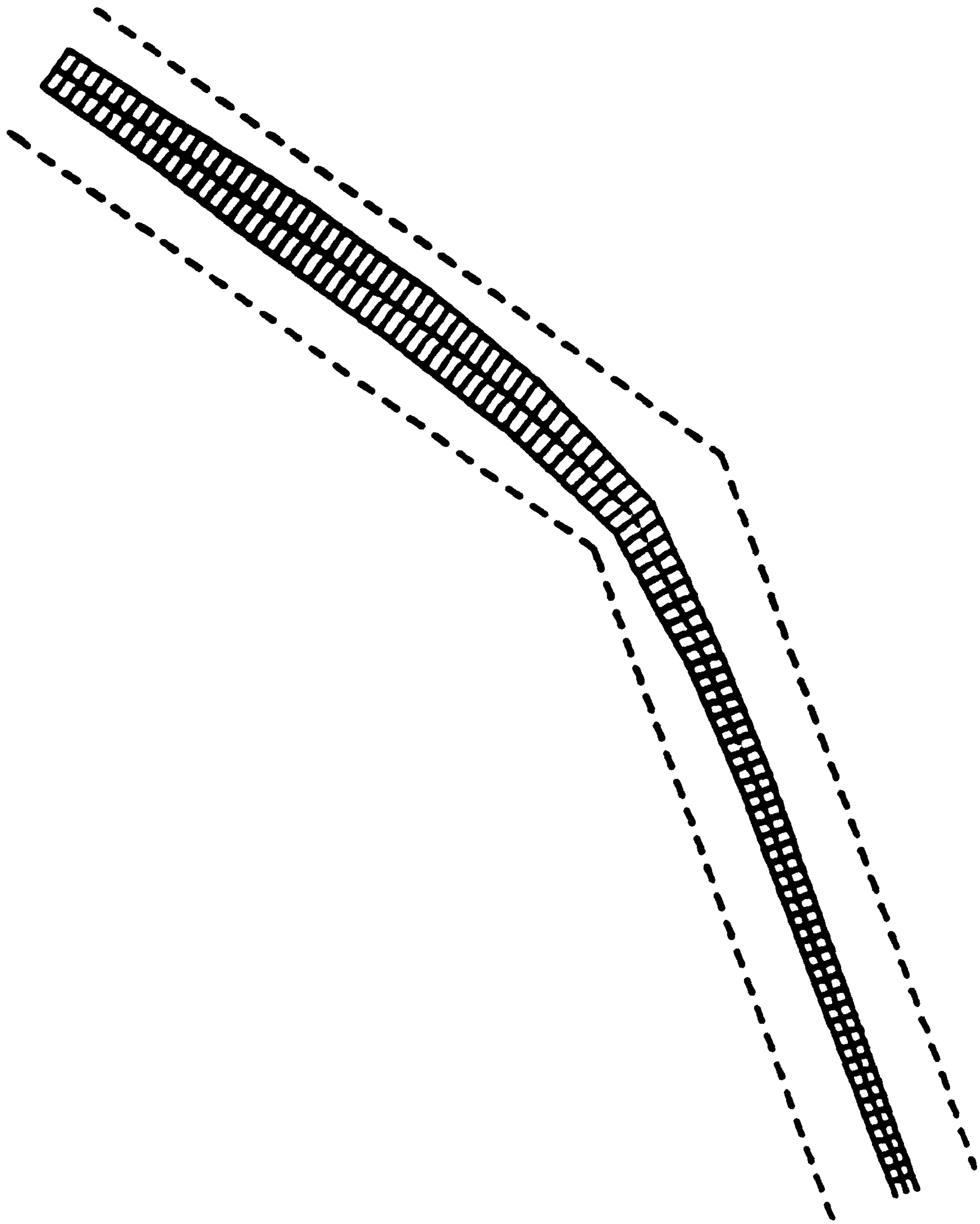


Figure D-28. GRAPHIC Display, Relative Motion, Track-Up, Course Vector, Scaled Ship Image

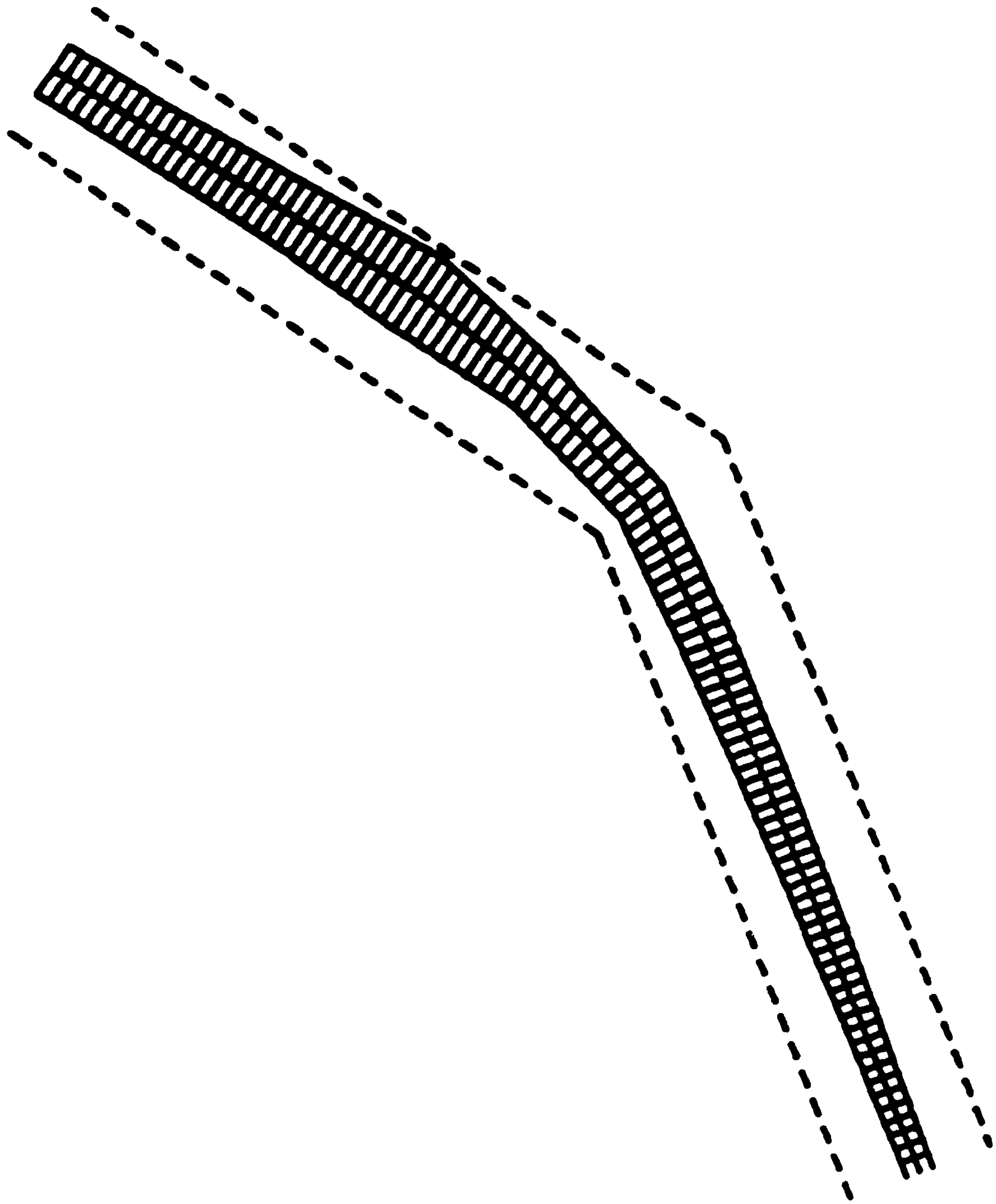


Figure D-29. GRAPHIC Display, Relative Motion, Track-Up, Course Vector, Symbolic Ship Image

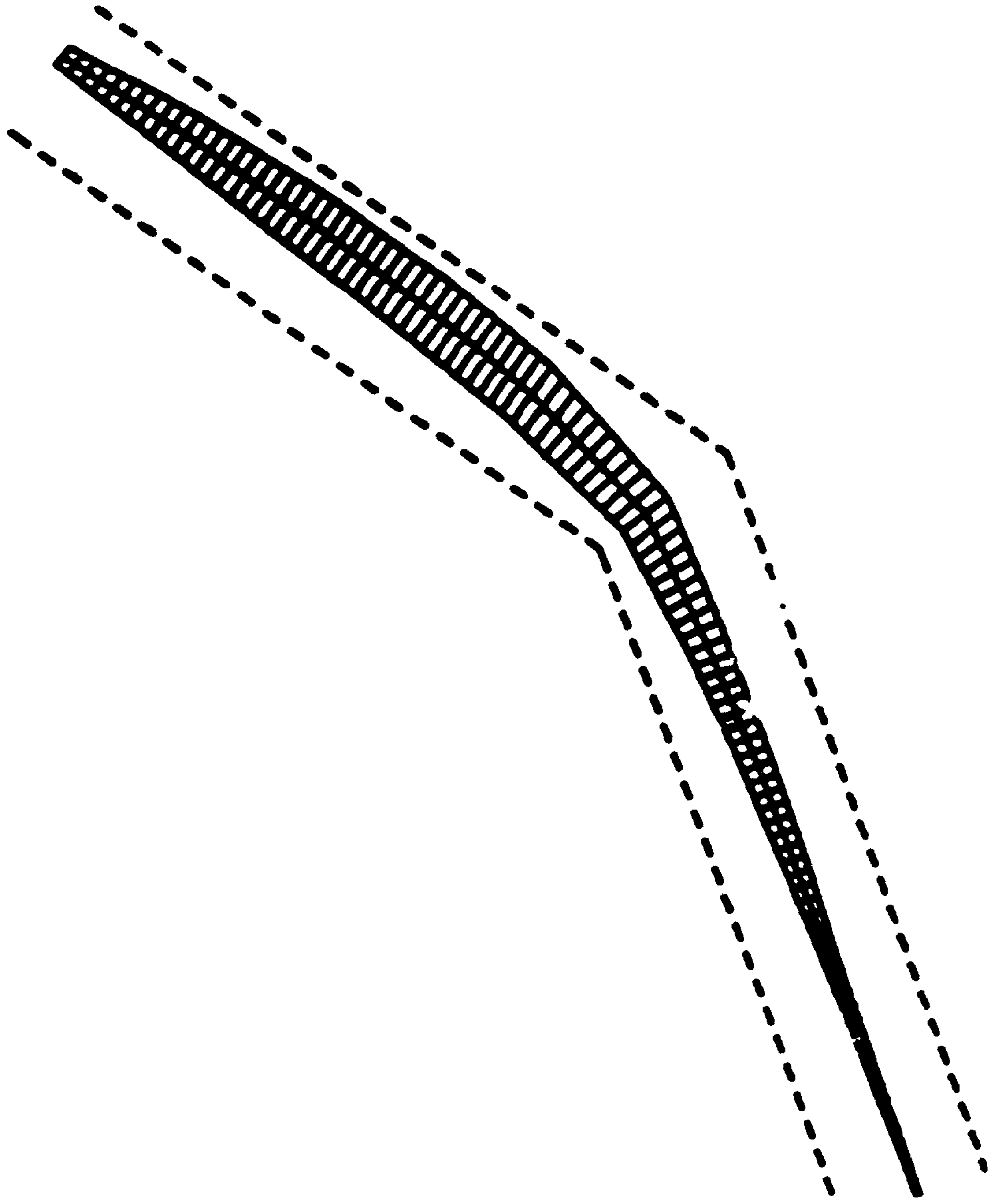


Figure D-30. GRAPHIC Display, Relative Motion, Head-Up, Heading Vector, Scaled Ship Image

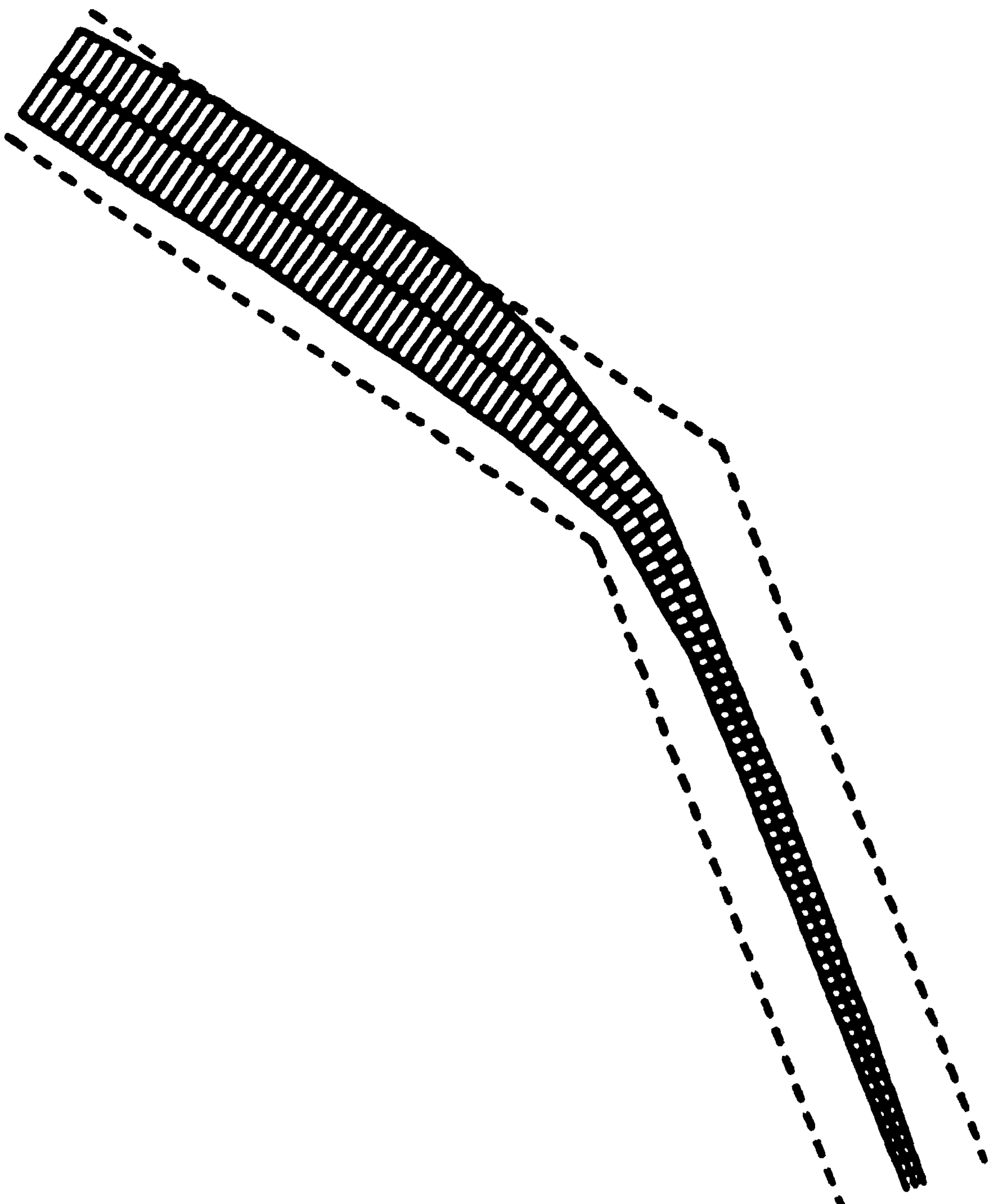


Figure 3-31. [illegible] Display, Relative Motion, Head-Up, Course Vector,
Scaled Ship Image

Section A2

PERSPECTIVE DISPLAY VARIABLES COMBINED PLOTS

Data in this section allow comparison of the principal perspective display variables

- 60° field of view
- 30° field of view

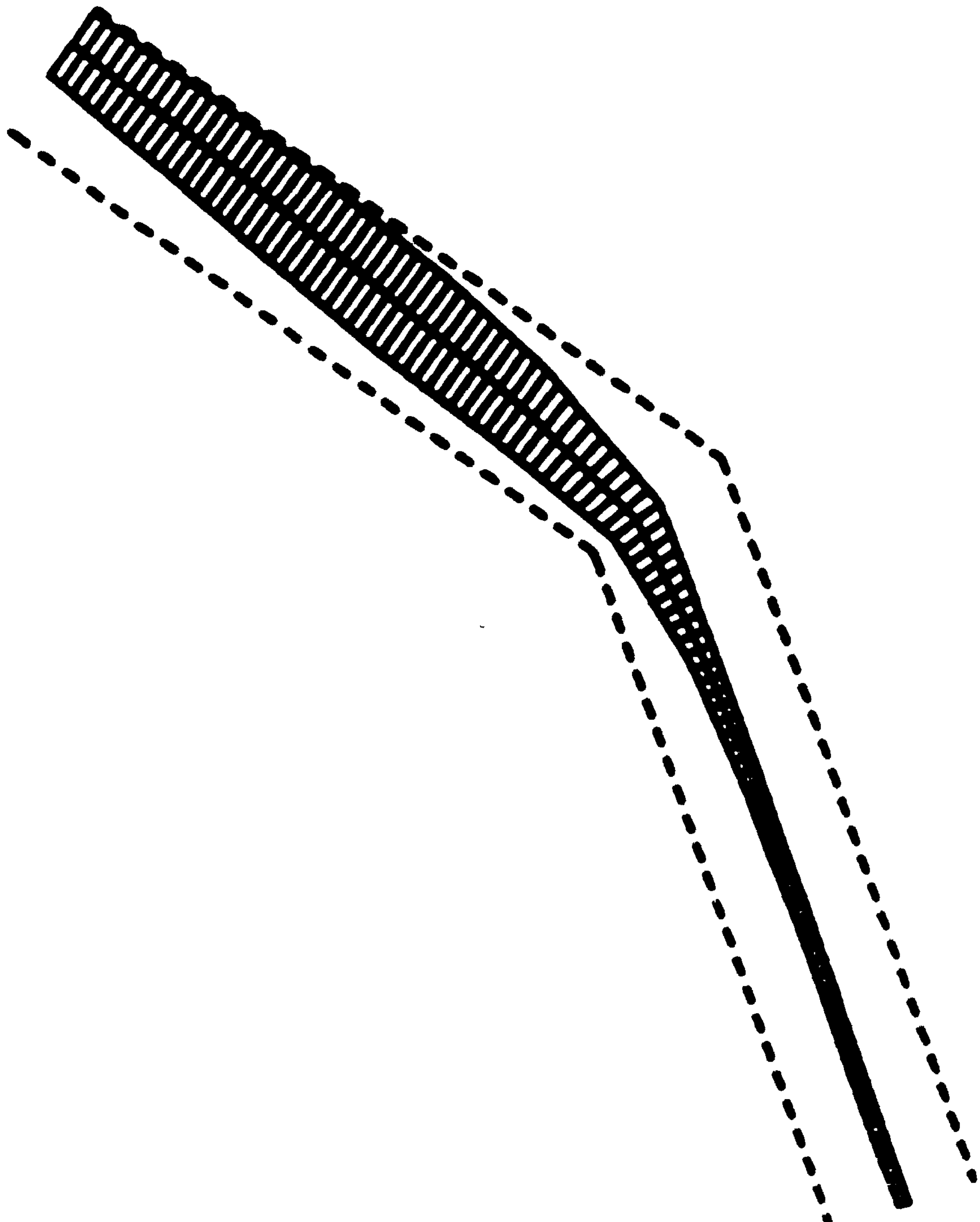


Figure 3-32. PERSPECTIVE Display, 60-Degree Field of View

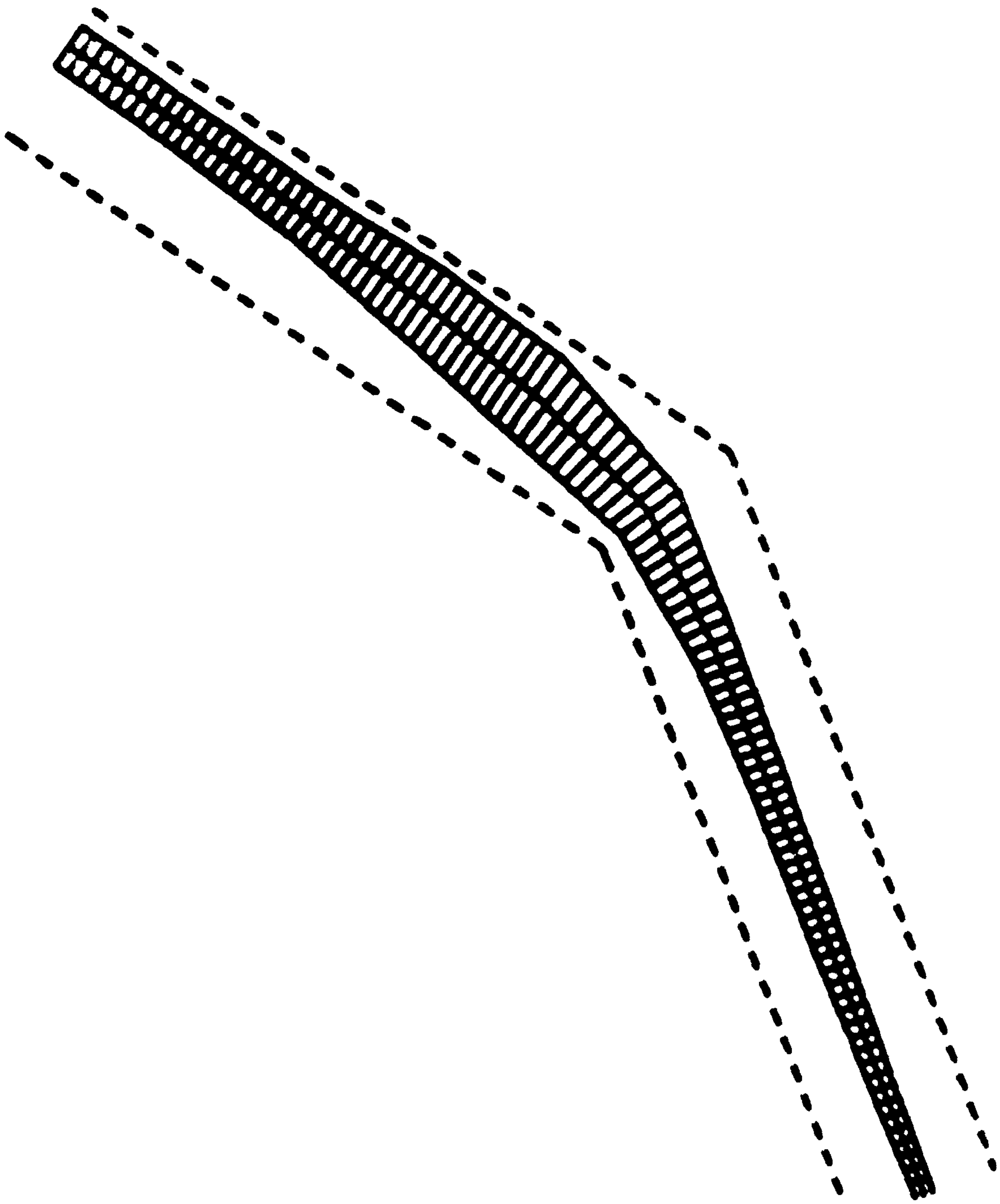


Figure 3-33. PERSPECTIVE Display, [illegible] Field of View

BIBLIOGRAPHY

CAORF Research Staff, Simulator Evaluation of Predictor Steering, Short Range Collision Avoidance and Navigation Displays, Report Number CAORF 30-7913-01, National Maritime Research Center, Kings Point, New York, November 1979.

CAORF Research Staff, Valdez Operational Exercises, National Maritime Research Center, Kings Point, New York, August 18, 1977.

Eclectech Associates, Inc., Aids to Navigation Presimulation Report, AN-CAORF, United States Coast Guard, September 1979.

Eclectech Associates, Inc., Aids to Navigation Presimulation Report, AN-Visual Experiment, United States Coast Guard, October 1979.

Eclectech Associates, Inc., AN-CAORF Preliminary Observations, United States Coast Guard, December 1979.

United States Coast Guard, An Approach to the Study of Electronic Displays for Use in Restricted Waterways, a position paper, December 1979.

ATE
LMED
— 8